Naval Health Research Center

FINAL REPORT OF THE EPIDEMIOLOGY OF WHITE BLOOD CELL COUNTS AT THE NAVAL WEAPONS CENTER CHINA LAKE, CALIFORNIA 1982-83

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Final Report of the Epidemiology of White Blood Cell Counts at the Naval Weapons Center China Lake, California 1982-83

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Summary

Problem

In 1977 the Centers for Disease Control (CDC) conducted a study that found six cases of leukemia during a five-year period in children under 19 years old living in Ridgecrest, California, the community that borders the Naval Weapons Center (NWC). CDC could not determine any common causal factors for the six cases and the cluster was considered a random clustering in time. Because of the proximity of NWC to Ridgecrest, CDC was asked to review the hematological records of 860 employees who were involved in an ongoing Occupational Health Program. Sixty-six cases of low white blood cell (WBC) counts were ascertained, 35 of which were chronic. These cases occurred over a 20-year period. It was decided that there was a need for a center-wide surveillance program to detect any evidence of myelosuppression among all NWC employees (approximately 4,580).

Objectives

The objectives of the study were: (1) to develop a hematological profile of white blood cell counts in the workforce at NWC, (2) to use this profile to determine the prevalence rate of leukopenia at NWC, and (3) to determine if occupational exposures may be associated with any observed decreases in white blood cell counts.

Approach

A complete blood cell count with a differential (WBC) count was performed on all employees who volunteered for the study during 1982-83. Each volunteer was asked to answer a short questionnaire prior to giving a blood sample. If on the first blood draw a subject's WBC count was less than or equal to 4,500 cells per mm^3, the person was recalled for a second WBC count one month later. If the second WBC count was also less than or equal to 4,500 cells per mm^3, the person was recalled one month later for a third test. If the results of all three tests were at or below this level, the person was considered to have a persistent low WBC

count and was referred to the Naval Hospital, San Diego for a bone marrow biopsy with extensive evaluation of bone marrow function.

Results

Approximately 66 percent of the Center's workforce participated in the study. The mean WBC count for the entire NWC population was 6,900 cells per mm^3. There was no consistent trend in mean WBC counts according to age, sex, or length of employment at NWC. Current cigarette smokers had a markedly higher mean WBC count (8,400 cells per mm^3) than never smokers (6,200 cells per mm^3). On the first blood draw 222 (7.4%) participants had a WBC count below 4,500 cells per mm^3; of those, 35 (1.2%) remained low after three blood draws. When analyzed by grouped work codes, the Electronic Warfare Department had both crude and smoking-adjusted prevalence rates of low WBC counts which were nearly double that of the total NWC population, a difference that was statistically signficant. Within the Electronic Warfare Department, the Microwave Development Division had a crude and smoking-adjusted prevalence rate of approximately 3.5 times the corresponding rate in the total NWC population. This finding was statistically significant before and after adjusting for smoking. Crude and smoking-adjusted prevalence rates were determine for 26 work locations based on similarity of activities; of these only Thompson Laboratory had a crude rate significantly higher than that observed for all other work locations. However, this excess was consistent with the presence of Electronic Warfare Department staff in this building.

Conclusions

There is no apparent environmental exposure affecting all NWC employees. The Electronic Warfare Department had more cases of low WBC counts than would have been expected based on the entire NWC population, and the prevalence rate in this department (14.6%) was significantly higher than in the total NWC population (7.4%). The Electronic Warfare Department also had the highest prevalence rate (3.0%) of persistent cases of low WBC counts compared to the total NWC population (1.2%). However, these rates for persistent low WBC counts were based on few cases and were not statistically significant. The prevalence rate of low WBC counts in Thompson Laboratory (16.2%) was significantly higher than in the total NWC population (7.4%). This is consistent with the high prevalence rate in employees of the Electronic Warfare Department, who comprised nearly 90 percent of participants from Thompson Laboratory. The high rate of low WBC counts in the Electronic Warfare Department is due to the statistically significantly high rate (26.0%) in the Microwave Development Division which shows a marked shift toward lower WBC counts.

Introduction

The Naval Health Research Center in San Diego in collaboration with the Naval Weapons Center (NWC), China Lake, California, conducted a hematological monitoring program for all NWC employees. Objectives of the program included development of a hematological profile of the work force at NWC and evaluation of the health significance of the profile. This report provides results of analyses of 3,012 volunteers who gave blood for the study between February 1, 1982 and March 15, 1983.

Background

In 1977, the Centers for Disease Control (CDC) was contacted by a Los Angeles physician and informed of an apparent clustering of leukemia in children living in Ridgecrest, California, the community that borders the Naval Weapons Center. CDC conducted a study that found six cases of leukemia during a five-year period in children under 19 years old living in Ridgecrest. Only 1.3 cases would have been expected during five years in a population of that size. However, no cases were determined to have occurred in the previous ten-year period. CDC could not determine any common causal factors for the six cases and, as a result, the cluster was considered to be a random clustering in time. Because of the close proximity of Ridgecrest, NWC was interested in the CDC study. As a result of this interest, CDC reviewed the hematological records of 860 employees who were involved in an ongoing Occupational Health Program at NWC. CDC ascertained 66 cases of leukopenia (low white blood cell counts) 35 of which were chronic occurring over a 20-year period. There was also concern expressed by employees and the Navy that there might be undetermined factors present that could be affecting all employees--not just those known to have exposures which could suppress bone marrow funccion. It was therefore coacluded that there was a need for sustained surveillance for evidence of myelosuppression among the NWC work force and that this surveillance should be extended to all employees (approximately 4,580).

An early step in this study was the selection of a case definition of leukopenia. For this study, a white blood cell (WBC) count of $\leq$ 4,500 cells per mm^3 was selected as the definition of leukopenia. This is a cut-off value of high sensitivity and was selected to insure inclusion of the greatest number of individuals who might be considered leukopenic. A WBC count at or below this level, however, is not necessarily pathologic and may be within the range of normal variation (1,2,3).

We were interested in identifying people with leukopenia because (1) leukopenia may be evidence of an exposure that could affect the hematopoetic system in a transitory way, but could possibly increase susceptibility to infectious disease; (2) it may indicate a condition that could predispose to a more serious illness at a later time; or (3) it may be the first diagnostic indication of a more serious condition, for instance, a neoplastic disease such as leukemia.

In order to examine the prevalence of leukopenia in the NWC population and to evaluate its meaning, a two-phase study design was adopted.

Study Design

An annual complete blood cell count with a differential white blood cell (WBC) count was performed on all NWC employees who volunteered for the program. If on the first WBC count a subject's count was less than or equal to 4,500 cells per mm^3, the person was recalled for a second WBC count one month later. If the second WBC count was also less than or equal to 4,500 cells per mm^3, the person was recalled a month later for a third test. If results of all three tests were below this level the person was considered to have chronic leukopenia and was referred to Balboa Naval Medical Center in San Diego, California for an extensive evaluation of bone marrow function, including a bone marrow biopsy.

This study was both part of the NWC occupational health program and a research project. Its objectives included: (1) identification of individual employees with low WBC counts, (2) determination of the prevalence of low WBC counts within the work force, and (3) evaluation of the health significance of the observed prevalence, whether indicative of a possible health hazard to particular subgroups or to the entire work force at NWC.

As has been noted above, voluntary participation was sought. Each volunteer was asked to give a 7 ml sample of blood and answer a short questionnaire. The questionnaire obtained personal data including name, social security number, age, race, sex, a brief smoking history, and a limited NWC work history. The work history included the time periods, work locations, and job title(s) held for the entire period that the employee worked at NWC. This questionnaire was completed at the time the initial blood sample was drawn.

All blood samples were collected between 8:30 and 11:00 a.m. because previous studies have reported variation in WBC counts from morning to evening (3,4). The exact time at which the sample was taken was recorded. Each sample, as it was drawn, was immediately tagged with an adhesive label that had a bar code number which enabled it to be optically read by electronic equipment. This bar code number was also attached to the questionnaire, entered in a blood sample log, and affixed to a laboratory report form.

Introduction of a program such as this would have overloaded the existing capabilities of the small branch medical clinic at NWC. Automation was the most practical approach to the large-scale hematological analysis required by this project. Therefore, a Technicon H6000, an automated blood cell analyzer, was acquired. This machine is a self-contained blood analyzer and computer system. It optically read the bar code number of each blood sample, performed a complete blood cell count and a differential white blood cell count, and recorded the results.

The Technicon was interfaced directly with a VAX 11/750 computer. This eliminated the need for manual data entry of blood analysis results, and allowed for rapid, accurate, and convenient linking of individual blood analyses with data concerning personal characteristics and job-related activities obtained from the questionniare.

Mean white blood cell counts and standard deviations were calculated according to age, race, sex, smoking status, duration of employment at NWC, job classification and work location. Prevalence rates for study subjects with white blood cell counts $\leq 4{,}500$ cells per mm^3 were determined according to these same variables. Prevalence rates by job classification and work location were adjusted for differences in smoking by the direct method (5). Confidence limits were calculated and statistical significance determined, using the normal distribution (5). All probability values reported are two-tailed.

Quality Control

The most technically advanced white blood cell counter in existence, the Technicon H6000, and the most widely used, the Coulter Counter, were used in this study to guarantee the reliability of the findings. Every fourth blood sample taken was tested both on the Technicon H6000 and the Coulter Counter Model ZBI. The Coulter® Counter is used in thousands of hospitals and has been used in numerous surveys, including the U.S. National Health and Nutrition Examination Survey--the HANES survey (6,7). The HANES survey was conducted by the U.S. National Center for Health Statistics and reported on white blood cell counts for a probability sample of 5,500 Americans from throughout the United States. Figure 1 shows the high agreement between the two machines. Since these machines work on different principles, this

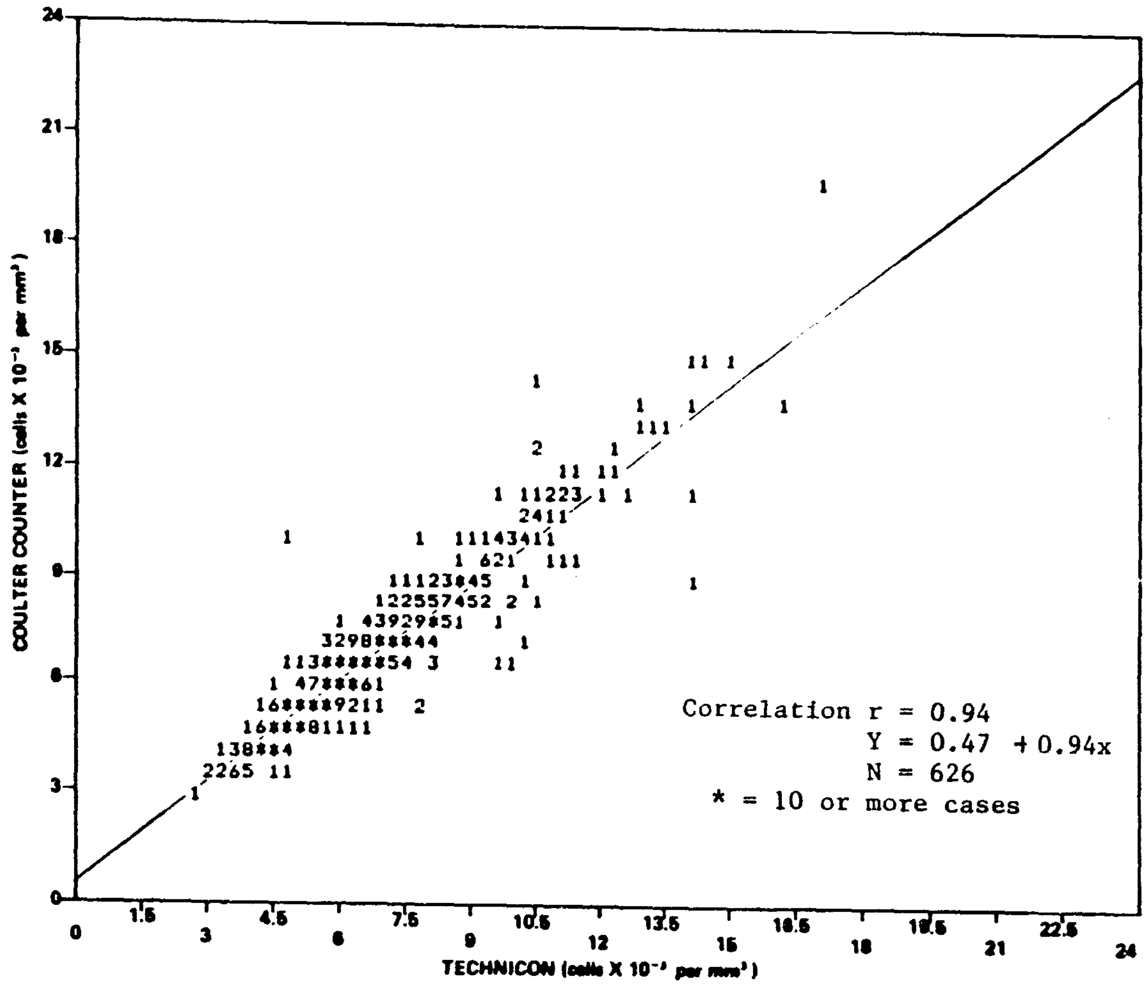


Figure 1. Scatter plot of the correlation between WBC counts on the Technicon H6000 and Coulter Counter ZBI

high level of agreement provides confidence in the accuracy of the cell counts obtained.

Results

Section I - Demographic Characteristics and Comparison with U.S. Population

1. Demographic characteristics. A total of 3,012 of the 4,581 employees of the Naval Weapons Center (66%) provided samples of blood and completed questionnaires. Rates of participation by grouped work code are shown in Appendix A Table A1.

The frequency distribution by age of the 3,012 participants is shown in Table 1. Approximately 80% were between 25 and 54 years old and about 60% were between 35 and 54 years. About 70% of participants were males and 30% were females. Over 90% of study participants were white.

Table 1. Frequency distribution of participants by age, Naval Weapons Center, China Lake, 1982-83

Age (years)	No.	Percent
15 - 24	151	5.0
25 - 34	602	20.0
35 - 44	918	30.5
45 - 54	849	28.2
55 - 64	394	13.1
65+	98	3.4
Total	3,012	100.0

Table 2 shows the distribution of participants by cigarette smoking status at the time of the survey. About one-quarter of the population were current cigarette smokers, about one-quarter were former smokers, and about one-half never smoked.

Table 2. Frequency distribution of participants by cigarette smoking status, Naval Weapons Center, China Lake, 1982-83

Cigarette smoking status	No.	Percent
Never	1,332	44.2
Former	820	27.2
Current	825	27.4
Unknown	35	1.2
Total	3,012	100.0

The distribution of participants by length of employment at NWC is shown in Table 3. Over one-half of the study's participants had been at NWC for more than 10 years, and nearly 70 percent had been there five or more years.

Table 3. Frequency distribution of participants by length of employment at the Naval Weapons Center, China Lake, 1982-83

Length of employment at Naval Weapons Center (years)	No.	Percent
0 - 1.9	162	5.4
2 - 4.9	649	21.5
5 - 9.9	454	15.1
10+	1,576	52.3
Unknown	171	5.7
Total	3,012	100.0

2. Effects of demographic characteristics. There was no consistent trend in mean white blood cell count according to age (Table 4).

3. Effects of cigarette smoking. Mean white blood cell counts were analyzed by smoking status (Table 5). Current smokers have a markedly higher mean white blood cell count (8.4×10^3 cells/mm^3) than do former smokers (6.5×10^3 cells/mm^3) or never smokers (6.2×10^3 cells/mm^3). There was a difference of about 2,200 cells/mm^3 between the current-and never-smoker groups. Smoking status was, therefore, an important factor in comparisons of mean white blood cell counts.

Table 4. Mean white blood cell count according to age, Naval Weapons Center, China Lake, 1982-83

Age (yr)	White blood cell count $\times 10^{-3}/mm^3$ Mean	Standard Deviation	No.
15 - 24	6.8	1.8	151
25 - 34	6.9	2.0	602
35 - 44	6.8	2.1	918
45 - 54	7.0	2.1	849
55 - 64	6.9	2.0	394
65 +	6.7	2.4	98
Total	6.9	2.1	3,012

Table 5. Mean white blood cell count according to smoking status, all races, both sexes, Naval Weapons Center, China Lake 1982-83

Smoking Status	White blood cell count x $10^{-3}mm^3$ Mean	Standard Deviation	N
Never	6.2	1.6	1,332
Former	6.5	1.6	820
Current	8.4	2.4	825
Total*	6.9	2.1	2,977

*Excludes 35 subjects for whom smoking status was unknown.

Figure 2 is a plot of the distribution of white blood cell counts for current smokers and non-smokers. There was a marked difference between the distributions of the two groups: smokers had higher white blood cell counts and a more dispersed and irregular distribution. This difference has been observed in other studies, including the HANES (6,7).

Figure 3 is a plot of the distribution of white blood cell counts for former-smokers and never-smokers. There was little difference in the distributions. Former- and never-smokers were therefore grouped into the category of non-smokers for other analyses.

Figures 4 (current smokers) and 5 (non-smokers) show no consistent trend of mean WBC count by length of employment at NWC.

There is a striking similarity in means regardless of length of employment. For example, in Figure 5 (non-smokers) the mean is nearly the same for those working at NWC less than 2 years as for those working for more than 10 years.

4. Comparison of mean WBC counts with the National Health and Nutrition Examination Survey. The National Health and Nutrition Examination Survey (HANES) was conducted by the National Center

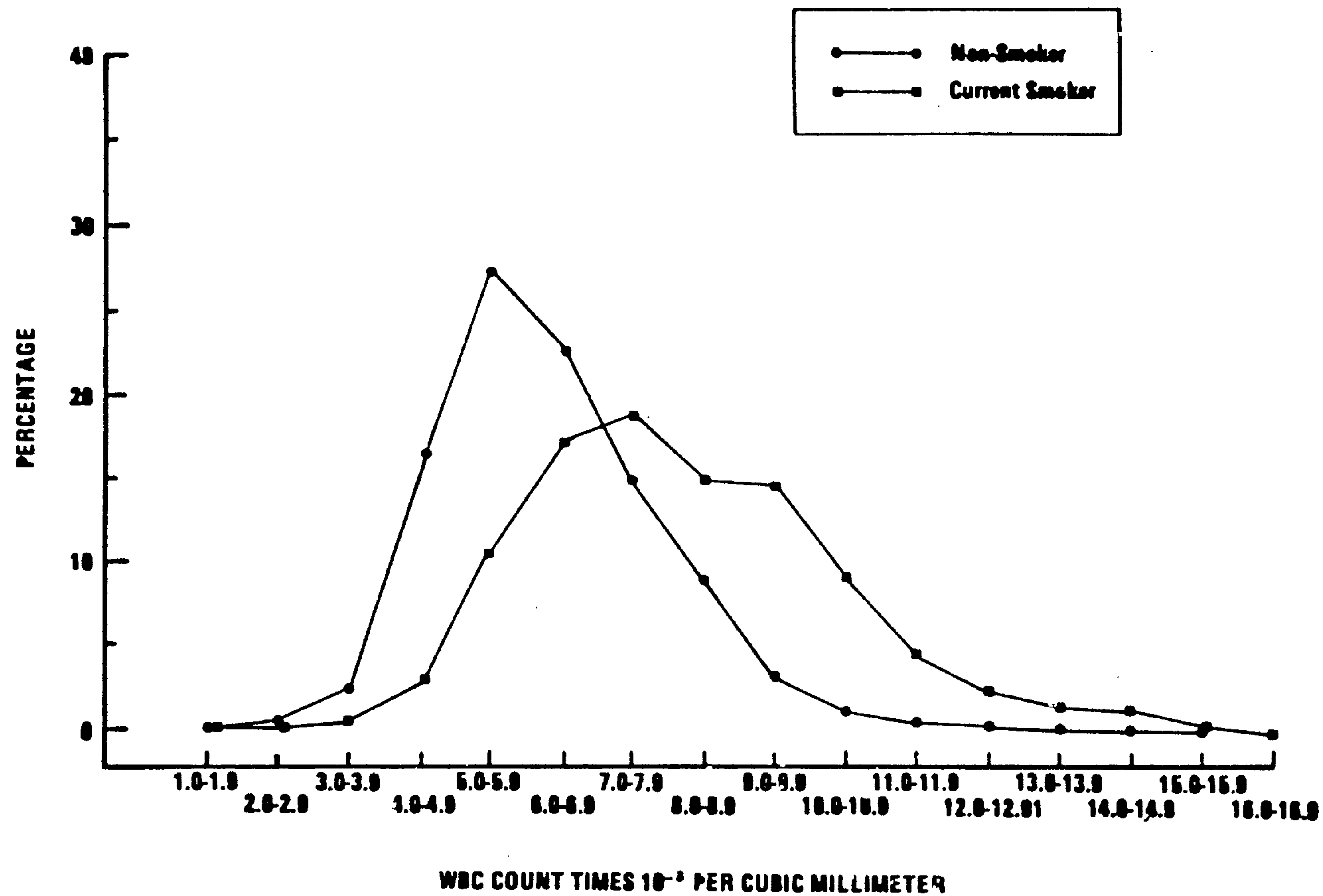


Figure 2. Distribution of white blood cell counts by current and nonsmokers, 3,012 participants, Naval Weapons Center

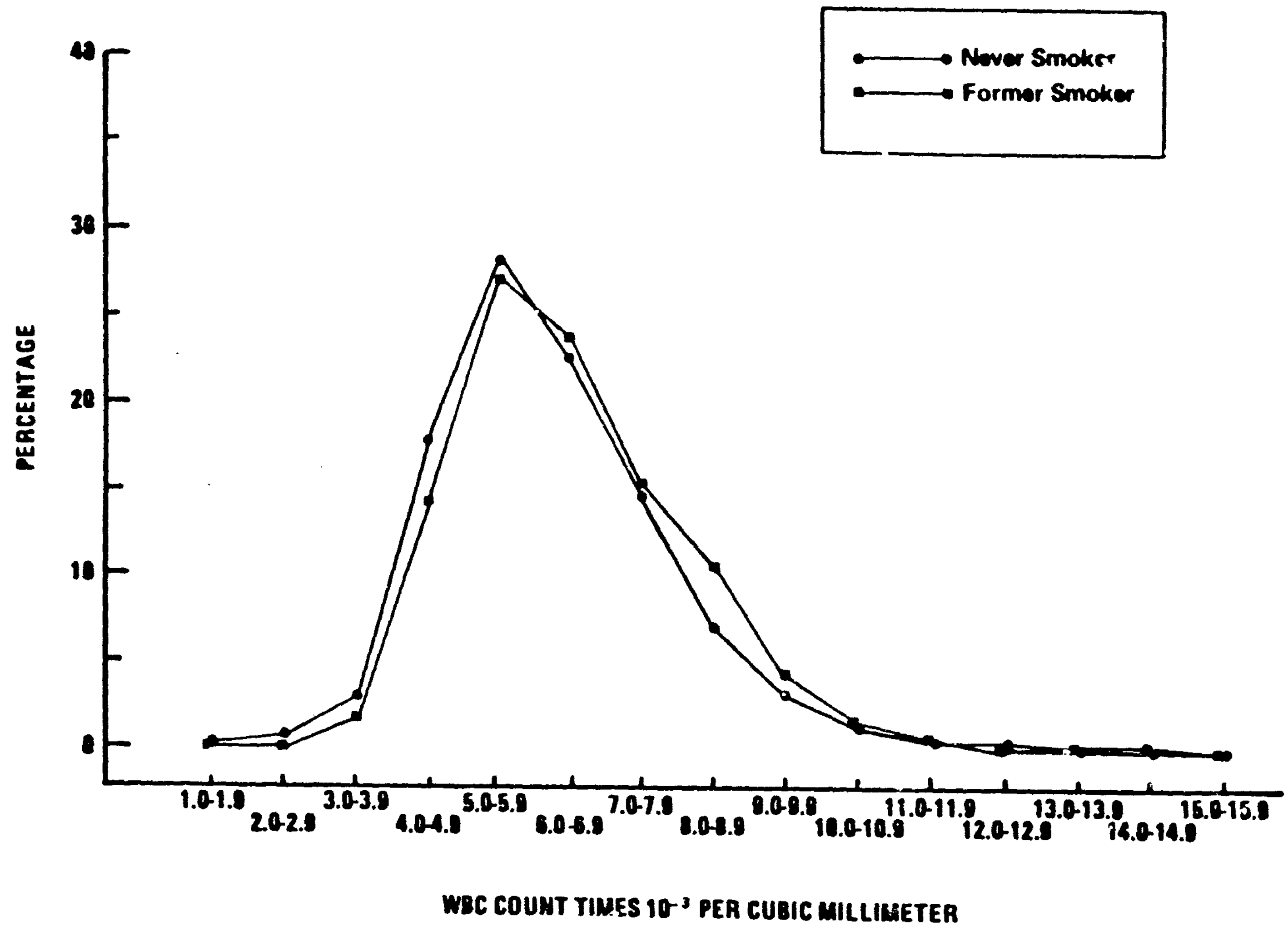


Figure 3. Distribution of white blood cell counts by never smoker and former smoker, 3,012 participants, Naval Weapons Center

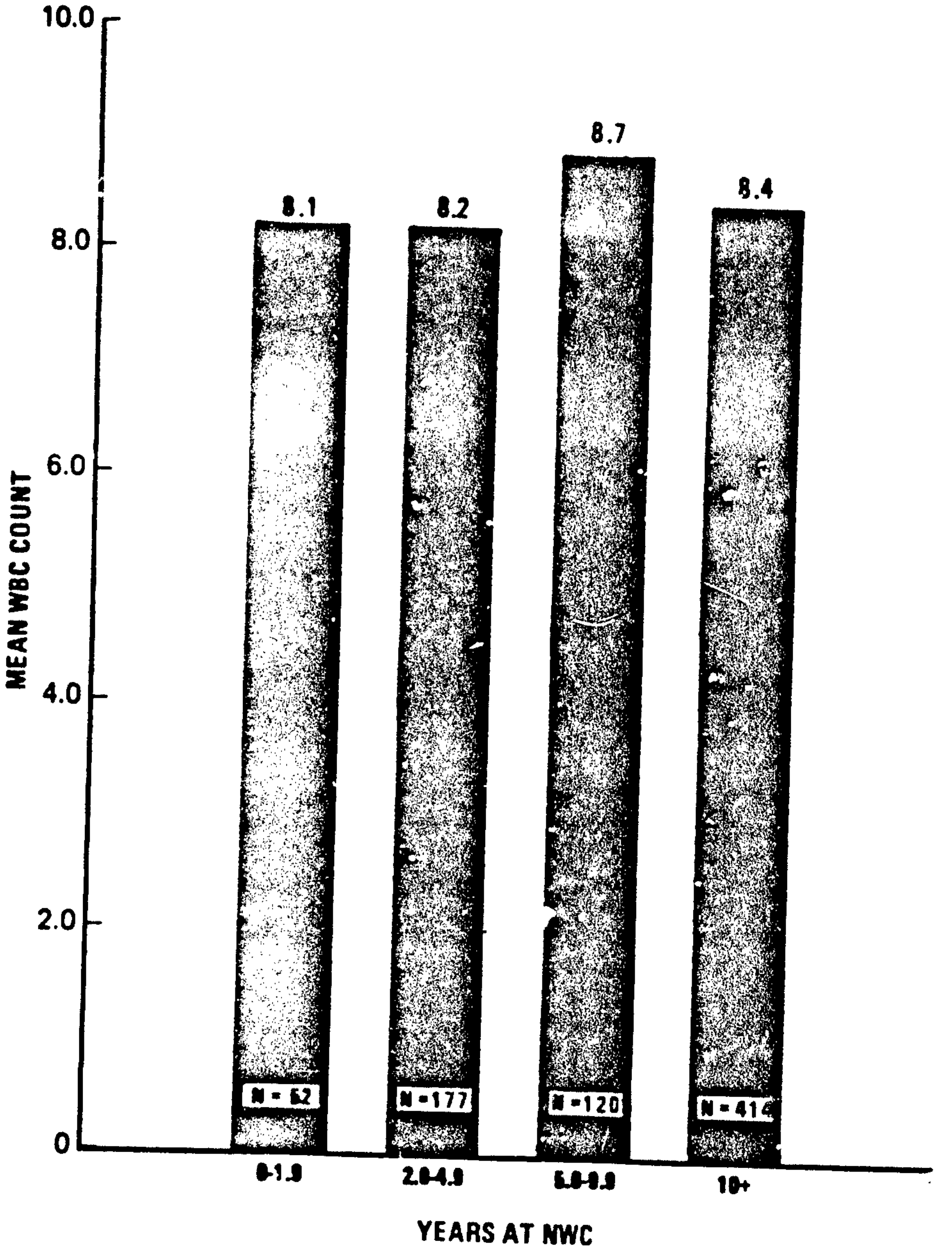


Figure 4. Mean white blood cell count by years at the Naval Weapons Center, current smokers

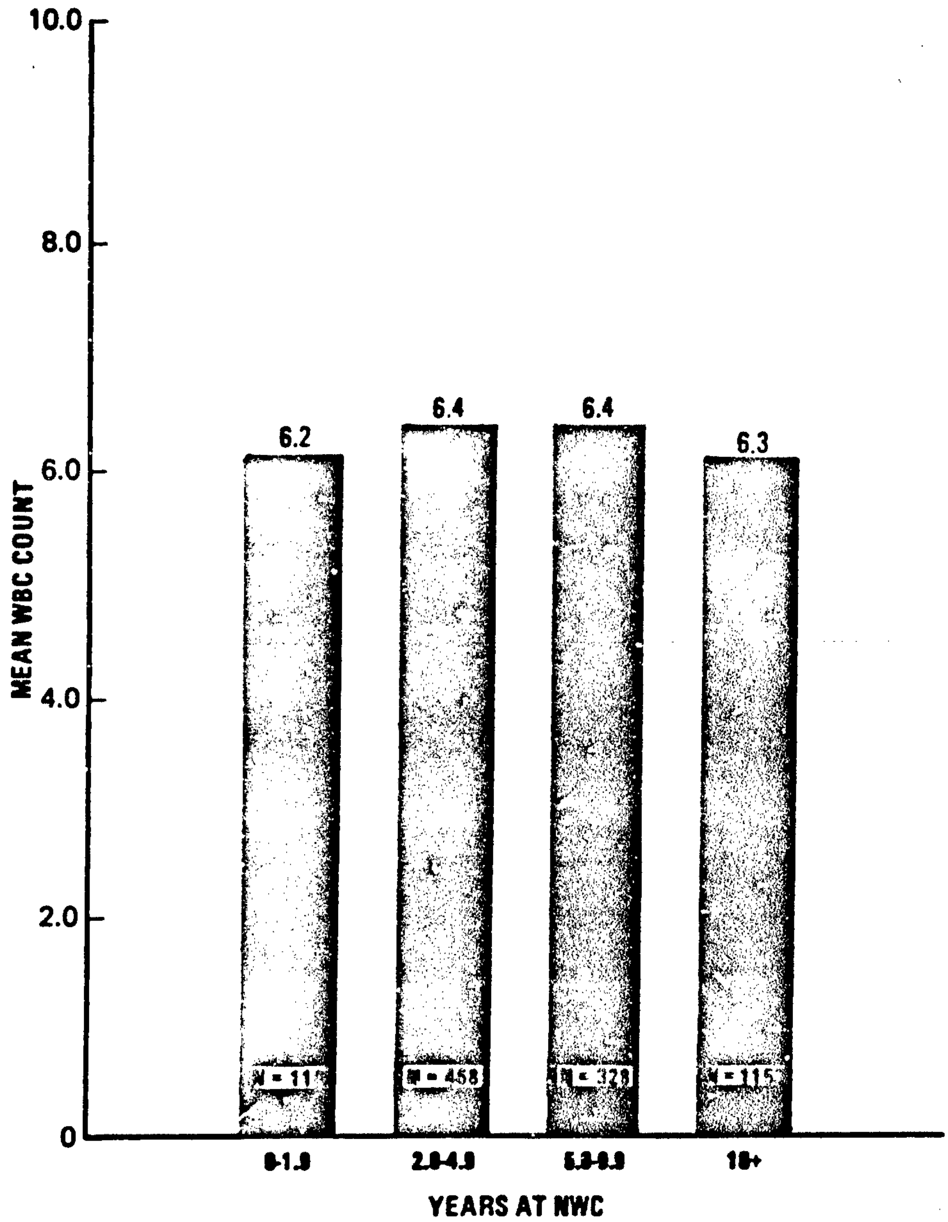


Figure 5. Mean white blood cell count by years at the Naval Weapons Center, non-smoker

for Health Statistics from 1971 to 1975 (6). This study reported WBC counts in a random sample of 5,500 Americans from throughout the United States. Results of the HANES are based on a single blood draw analyzed using a Coulter Counter. Mean WBC counts in the NWC population are also based on a single blood draw which was analyzed using the Technicon H6000, with a sample reliability check using a Coulter Counter. The high level of agreement between results obtained on the Technicon and the Coulter Counter is shown in Figure 1.

A comparison by smoking status of WBC counts obtained in the HANES and results from this study is shown in Figure 6. Both studies showed a pronounced effect of smoking. Mean WBC counts for current smokers in both populations were approximately the same, i.e., the mean WBC count in the HANES population was only 100 cells per mm^3 lower than that observed at NWC. Among never smokers, however, mean WBC counts obtained in the HANES are about 900 cells per mm^3 greater than the mean WBC count for never smokers at the Naval Weapons Center. A similar difference was observed for former smokers.

The distribution of WBC counts for the total NWC population and the HANES is shown in Figure 7. The HANES did not report distributions for smokers and non-smokers. The apparent difference in the distributions may, therefore, be attributable to differences in the proportion of smokers in the two populations. About 75% of NWC employees are non-smokers as compared to about 64% of the HANES population.

Section II - Questionnaires Obtained Exposure Categories

1. Effects of occupation. It was determined that smoking elevated the white blood cell count (Table 5). Because the proportion of smokers in occupational groups (work codes) varied, prevalence rates of low white blood cell counts were adjusted for the proportion of smokers in each category.

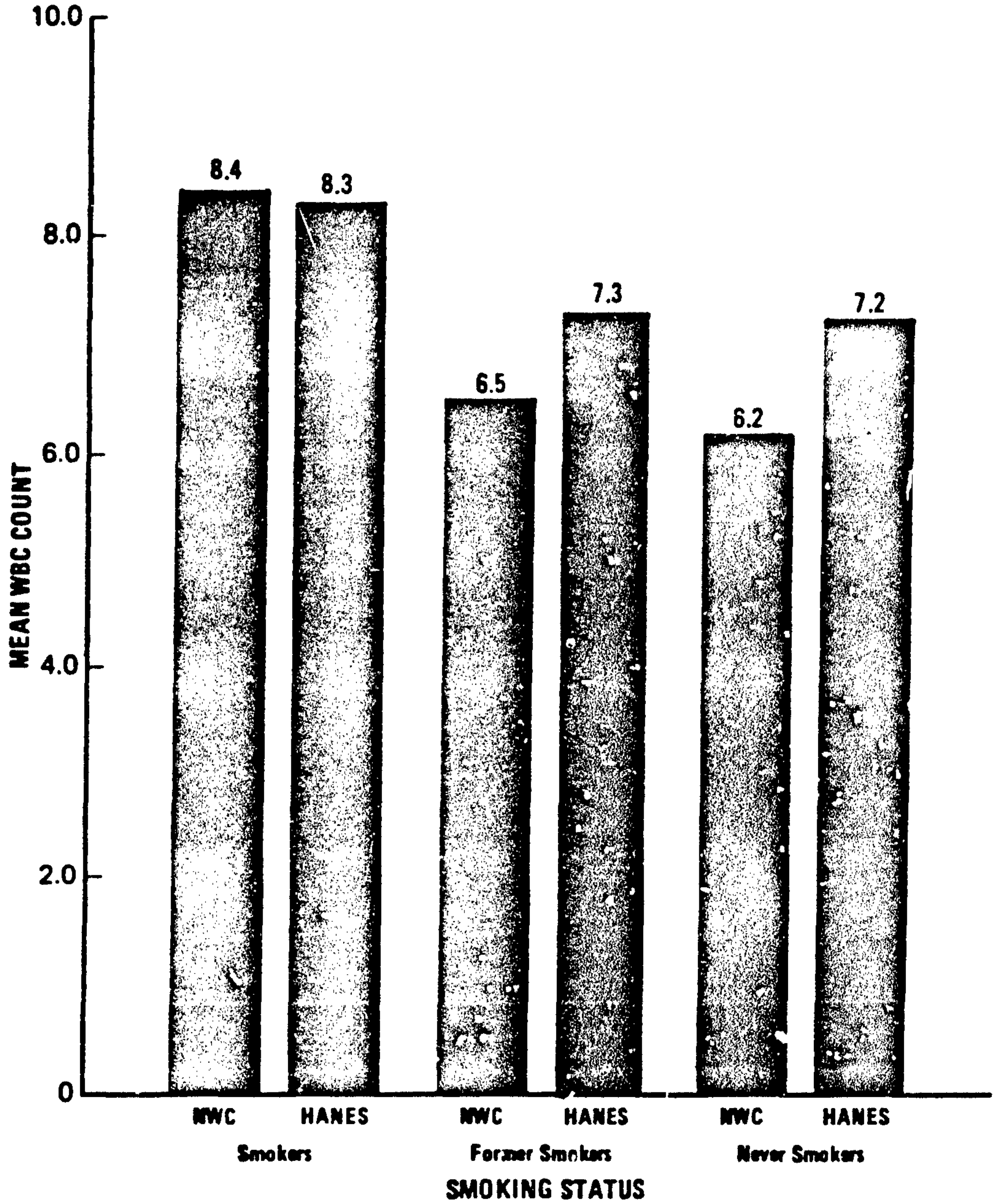
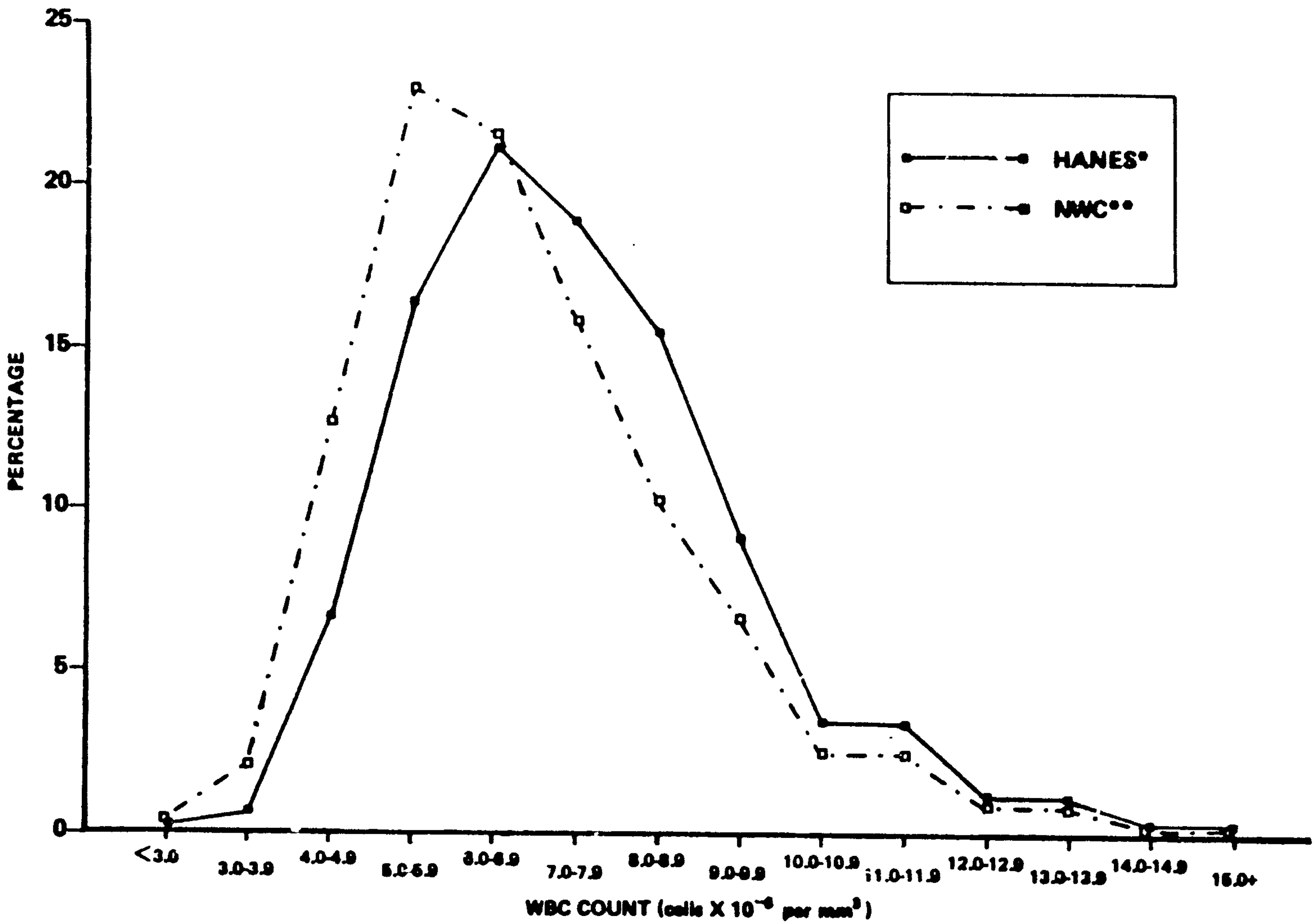


Figure 6. Mean white blood cell count by smoking status, Naval Weapons Center and HANES Survey



**White males ages 25 to 64, smoking status not reported*
***Total NWC population*

Figure 7. Distribution of white blood cell counts in HANES and NWC population

Table 6 shows the crude and smoking-adjusted prevalence rates of low white blood cell counts ($\leq$4,500 cells per mm^3), according to grouped work code. The same analysis by detailed work code is shown in Appendix A Table A2. Smoking-adjusted prevalence rates for grouped work code are shown in Figure 8. The Electronic Warfare Department had both crude and smoking-adjusted prevalence rates of low white blood cell counts which were about double that of the total NWC population, a difference that was statistically significant ($p \leq 0.05$ level). Crude and smoking-adjusted prevalence rates of low white blood cell counts by three divisions within the Electronic Warfare Department are shown in Table 7. Appendix B shows the NWC work codes in each division of the Electronic Warfare Department. The crude and smoking-adjusted rates in the Microwave Development Division are approximately 3.5 times the corresponding rate in the total NWC population. This finding was significant ($p \leq 0.05$) before and after adjustment for smoking. Participants from the Administration, System Sciences, and Radio Frequency Divisions experienced approximately twice the crude and smoking-adjusted rates as the total population (Figure 9). This finding was significant ($p \leq 0.05$) before adjustment for smoking but did not remain significant after adjustment. This may be due in part to loss of individuals whose smoking status was unknown and the consequent broadening of confidence intervals.

Mean white blood cell counts by twelve grouped work codes are shown in Table 8. The means are specific for smoking status, and the pronounced raising of mean WBC due to smoking can be seen in all work codes. Non-smokers in one grouped work code, the Electronic Warfare Department, had a mean white blood cell count that was significantly ($p \leq 0.05$) lower than the mean for the total NWC population. The mean WBC count for smokers and non-smokers combined in the Electronic Warfare Department was not significantly lower than the total population, however, because the mean for smokers was high (9.0×10^3 cells per mm^3).

Table 6. Crude and smoking-adjusted prevalence rates in percent initial low white blood cell counts ($\leq$4,500 cells per mm^3), according to grouped work code, Naval Weapons Center, China Lake, California, 1982-83

Grouped work code	No. of cases	No. of employee participants	Rate per 100 of WBC $\leq$4,500 cells/mm^3	95% Confidence limits Lower	95% Confidence limits Upper	Smoking-adjusted rate per 100 of WBC $\leq$4,500 cells/mm^3*	95% Confidence limits Lower	95% Confidence limits Upper
1. Administration	44	511	8.6	6.2	11.0	8.6	5.5	11.6
2. Medical clinic	2	48	4.2	0.0	9.8	5.2	0.0	13.3
3. Support departments	19	539	3.5**	2.0	5.1	4.0*	1.9	6.2
4. Research department	16	161	9.9	5.3	14.6	9.9	3.0	16.8
5. Engineering department	37	388	9.5	6.6	12.4	9.9	6.3	13.5
6. Aircraft weapons integ. dept.	15	206	7.3	3.7	10.8	6.8	1.9	11.7
7. Ordnance systems dept.	12	226	5.3	2.4	8.2	5.4	1.9	8.8
8. Fuze and sensors dept.	15	212	7.1	3.6	10.5	6.0	2.6	9.5
9. Electronic warfare dept.	35	240	14.6+	10.1	19.0	14.0+	8.6	19.4
10. Weapons dept.	7	227	3.1**	0.8	5.3	2.8**	0.4	5.2
11. Aircraft dept.	7	48	14.6	4.6	24.6	14.8	1.3	28.3
12. Range dept.	13	201	6.5	3.1	9.9	8.4	3.7	13.1
13. Unknown	0	5	0.0	0.0	--	0.0	0.0	--
Total NWC population	222	3,012	7.4	6.4	8.3	7.4	6.2	8.5

*Based on 2,977 individuals because 35 had unknown smoking status.

+Significantly high at the $p \leq 0.05$ level.

**Significantly low at the $p \leq 0.05$ level.

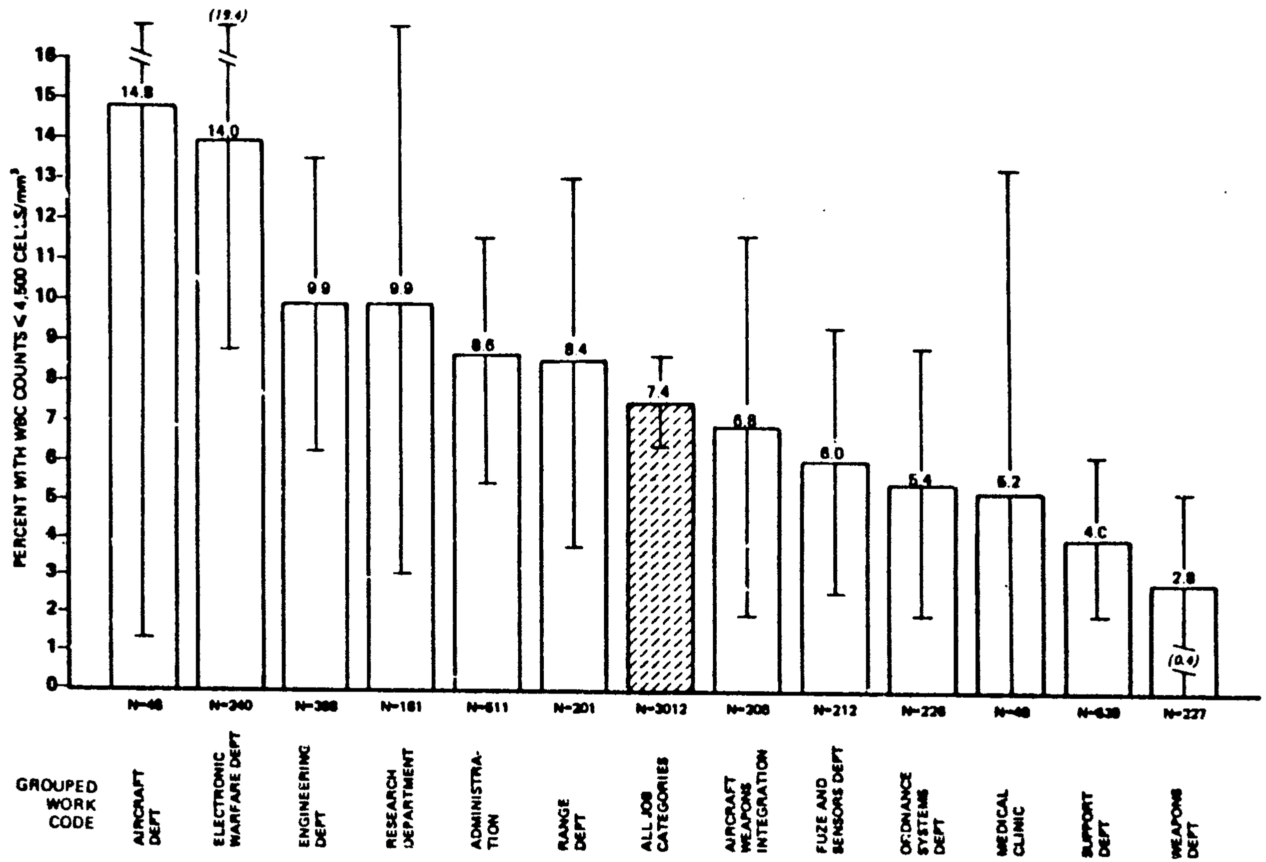


Figure 8. Smoking-adjusted prevalence rates of initial low white blood counts by grouped work code

Table 7. Crude and smoking-adjusted prevalence rates in percent, for low white blood cell counts ($\leq$4,500 cell per mm^3), according to division within the Electronic Warfare Department, Naval Weapons Center, China Lake, California, 1982-83

Electronic Warfare Department division	No. of cases	No. of employee participants	Rate per 100 of WBCC $\leq$4,500 cells/mm^3	95% Confidence limits		Smoking-adjusted rate per 100	95% Confidence limits	
				Lower	Upper		Lower	Upper
Administration, System Sciences, and Radio Freq.	20	128	15.6*	9.3	21.9	14.8	7.2	22.3
Microwave Development	13	50	26.0*	13.8	38.2	24.8*	8.6	41.0
Electronic Warfare Threat Environment Simulation (EWTES)	2	62	3.2+	0.0	7.6	3.9+	0.0	10.1
All	35	240	14.6*	10.1	19.0	14.0*	8.6	19.4
Total NWC population	222	3,012	7.4	6.4	8.3	7.4	6.2	8.5

*Significantly high at the $p \leq 0.05$ level.

+Significantly low at the $p \leq 0.05$ level.

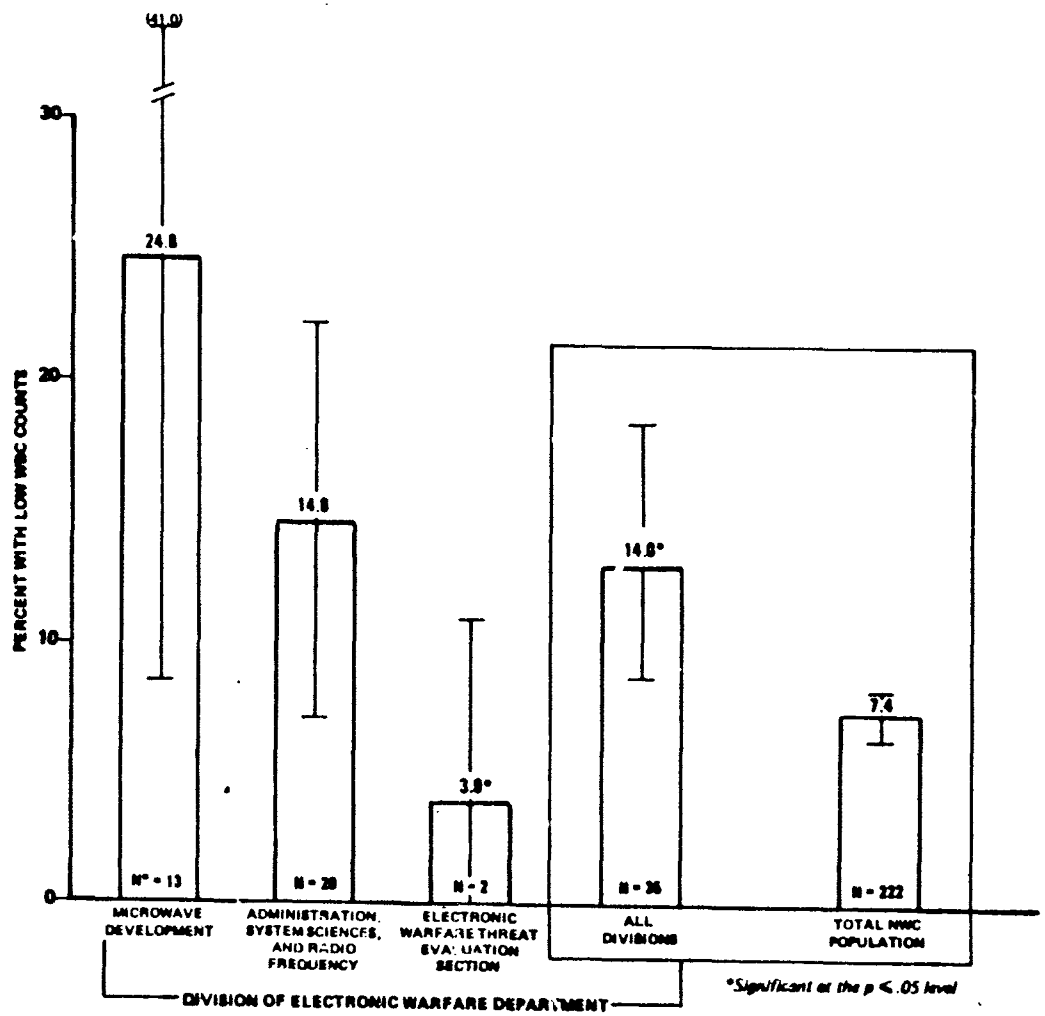


Figure 9. Percent of subjects in the Electronic Warfare Department with low white blood cell counts, by division, adjusted for smoking

Table 8. Mean white blood cell counts by grouped work code and smoking status,

Naval Weapons Center, China Lake, California, 1982-83

Grouped work code	Smoking Status											
	Current Smoker				Non-smoker				Total			
	No.	Mean WBC $\times 10^{-3}$ per mm^3	95% Confidence limits Lower	95% Confidence limits Upper	No.	Mean WBC $\times 10^{-3}$ per mm^3	95% Confidence limits Lower	95% Confidence limits Upper	No.	Mean WBC $\times 10^{-3}$ per mm^3	95% Confidence limits Lower	95% Confidence limits Upper
1. Administration	141	8.17	7.81	8.53	363	6.34	6.16	6.52	504	6.83	6.65	7.01
2. Medical clinics	16	8.89	7.71	10.07	28	6.39	5.85	6.93	44	7.24	6.60	7.88
3. Support departments	209	8.63	8.26	9.00	328	6.79+	6.61	6.97	537	7.48+	7.28	7.68
4. Research departments	32	7.87	7.05	8.69	129	6.15	5.90	6.40	161	6.49*	6.21	6.77
5. Engineering departments	116	8.07	7.71	8.43	269	6.16	5.96	6.36	385	6.73	6.53	6.93
6. Aircraft weapons integration	29	8.61	7.75	9.47	174	6.22	5.98	6.46	203	6.54*	6.28	6.80
7. Ordnance system department	59	7.75	7.30	8.20	161	6.32	6.09	6.55	220	6.71	6.49	6.93
8. Fuze and sensors department	31	8.86	8.08	9.64	180	6.26	6.05	6.47	211	6.64	6.39	6.89
9. Electronic warfare department	59	9.05	8.21	9.89	177	5.97*	5.71	6.22	236	6.73	6.40	7.06
10. Weapons department	48	8.22	7.56	8.88	179	6.28	6.08	6.48	227	6.69	6.46	6.92
11. Aircraft department	21	7.21*	6.29	8.13	27	5.70*	5.20	6.20	48	6.36	5.83	6.89
12. Range department	62	8.60	7.96	9.24	135	6.82+	6.48	7.16	197	7.38+	7.05	7.71
13. Unknown	2	--	--	--	2	--	--	--	39**	7.13	6.34	7.87
Total	825	8.36	8.24	8.56	2,152	6.34	6.27	6.41	3,012	6.90	6.82	6.97

*Significantly low at the $p \leq 0.05$ level

+Significantly high at the $p \leq 0.05$ level.

**Includes 35 with unknown smoking status.

Mean white blood cell counts in the Electronic Warfare Department, by division, are shown in Table 9. Non-smokers in the Administration, Systems Sciences, and RF Divisions combined, and the Microwave Development Division have means that are significantly lower ($p \leq 0.05$) than the total NWC population. In contrast, both current smokers and non-smokers in the Electronic Warfare Threat Evaluation Section have significantly higher means than corresponding groups in the total population.

2. Effects of work location. Twenty-six work locations were selected based on similarity of activities as determined by consultation with center personnel. The work location is self-reported, and many participants listed more than one location. The following tables and figures are based on the first work location listed. Work location questions were apparently misinterpreted by about 10 percent of respondents, who listed their work code number rather than their work location.

Crude and smoking adjusted rates by 26 work locations are shown in Table 10. A map of NWC showing the prevalence rates of low WBC counts by work location is shown in Figure 10. Of these only Thompson laboratory had a crude rate significantly higher than that observed for all work locations. This rate did not remain significantly higher after adjustment for smoking. The loss of significance of the adjusted rate may be in part attributed to a lower prevalence of smoking in this location (15.9%) as compared to the total NWC population (27.4%).

Table 11 shows the distribution of work codes within Thompson laboratory. Almost 90 percent of those reporting working in Thompson laboratory report working in the Electronic Warfare Department.

Mean WBC counts by work location were also calculated (Appendix A Table A3). Thompson laboratory and Michelson laboratory in areas other than one of five specified areas, had means statis-

Table 9. Mean white blood cell count by division of Electronic Warfare Department, Naval Weapons Center, China Lake, California 1982-83

Division of Electronic Warfare Department	Current smokers				Non-smokers				Total			
	No.	Mean WBC 10^{-3} per mm^3	95% Conf. limits Lower	Upper	No.	Mean WBC 10^{-3} per mm^3	95% Conf. limits Lower	Upper	No.	Mean WBC 10^{-3} per mm^3	95% Conf. limits Lower	Upper
Administration, system sciences, and RF	27	8.1	7.1	9.2	100	5.7*	5.4	6.0	127	6.2	6.0	6.4
Microwave development	9	7.9	5.8	10.0	40	5.2*	4.8	5.7	49	5.7*	5.4	6.0
EWTES	23	10.8+	9.5	12.1	37	7.3+	6.6	8.0	60	8.6+	8.2	9.0
Unknown	--	--	--	--	--	--	--	--	4**	--	--	--
All	59	9.2	8.4	10.0	177	6.0	5.9	6.1	240	6.8	6.4	7.1
Total NWC population	825	8.4	8.2	8.6	2,152	6.3	6.2	6.4	3,012¢	6.9	6.8	7.0

*Significantly low at the $p \leq 0.05$ level.
+Significantly high at the $p \leq 0.05$ level.
**All 4 had unknown smoking status.
¢Includes 35 with unknown smoking status.

Table 10. Crude and smoking-adjusted prevalence rates in percent, for low white blood cell counts ($\leq$4,500 cells per mm^3), according to work location, Naval Weapons Center, China Lake, California 1982-83

	Work location	Cases	No. of employee participants	Prevalence rate per 100 of WBCC $\leq$4,500 cells/mm^3	95% Confidence limits Lower	Upper	Smoking-adjusted rate per 100 of WBCC $\leq$4,500 cells/mm^3	95% Confidence limits Lower	Upper
1.	Administration bldg.	8	132	6.1	2.0	10.1	6.4	1.0	11.8
2.	Air facility	19	229	8.3	4.7	11.9	8.4	3.6	13.3
3.	Area R and extension	11	91	12.1	5.4	18.8	12.3	3.0	21.6
4.	CL pilot plant	5	58	8.6	1.4	15.8	9.3	0.3	18.2
5.	CLPP administration area	5	60	8.3	1.3	15.3	8.3	0.0	18.0
6.	CT/sky top area	1	36	2.8	0.0	8.1	2.9	0.0	9.4
7.	Echo range	3	64	4.7	0.0	9.9	5.3	0.0	12.1
8.	Fire station	6	55	10.9	2.7	19.1	14.9	1.5	28.2
9.	Lauritson laboratory	4	77	5.2	0.2	10.1	4.4	0.0	9.3
10.	Magazine area	1	8	12.5	0.0	35.4	5.5	0.0	24.0
	Michelson laboratory								
11.	Engineering labs	7	93	7.5	2.2	12.9	7.2	1.3	13.2
12.	Photography lab	3	26	11.5	0.0	23.8	11.4	0.0	25.4
13.	Propulsion lab	0	6	0.0	0.0	--	0.0	0.0	--
14.	Wing 4	1	43	2.3	0.0	6.8	2.1	0.0	7.0
15.	Wing 6	6	59	10.2	2.5	17.9	8.4	0.3	16.5
16.	Other	46	530	8.7	6.3	11.1	8.0	5.2	10.8

Table 10. (Cont'd)

	Work location	Cases	No. of employee participants	Prevalence rate per 100 of WBCC <4,500 cells/mm^3	95% Confidence limits Lower	Upper	Smoking-adjusted rate per 100 of WBCC ≤4,500 cells/mm^3	95% Confidence limits Lower	Upper
17.	Old dorm, personnel housing	11	171	6.4	2.8	10.1	6.7	2.2	11.1
18.	On the road	0	11	0.0	0.0	--	0.0	0.0	--
19.	Public works compound	3	97	3.1	0.0	6.5	3.1	0.0	7.0
20.	Ranges	13	135	9.6	4.6	14.6	10.4	3.9	16.9
21.	Safety and security	2	35	5.7	0.0	13.4	5.4	0.0	13.8
22.	Salt wells pilot plant	7	99	7.1	2.0	12.1	6.5	1.1	11.9
23.	Supply dept warehouse	0	55	0.0	0.0	--	0.0	0.0	0.0
24.	Solid state building	1	32	3.1	0.0	9.1	2.6	0.0	8.4
25.	Thompson laboratory	16	99	16.2*	8.9	23.4	14.9	5.2	24.6
26.	Other areas	23	276	8.3	5.1	11.6	7.5	3.7	11.3
27.	Unknown	20	435	4.6	2.6	6.6	--	--	--
	Total	222	3,012	7.4	6.4	8.3	7.4	6.4	8.3

*Significantly high at the $p \leq 0.05$ level.

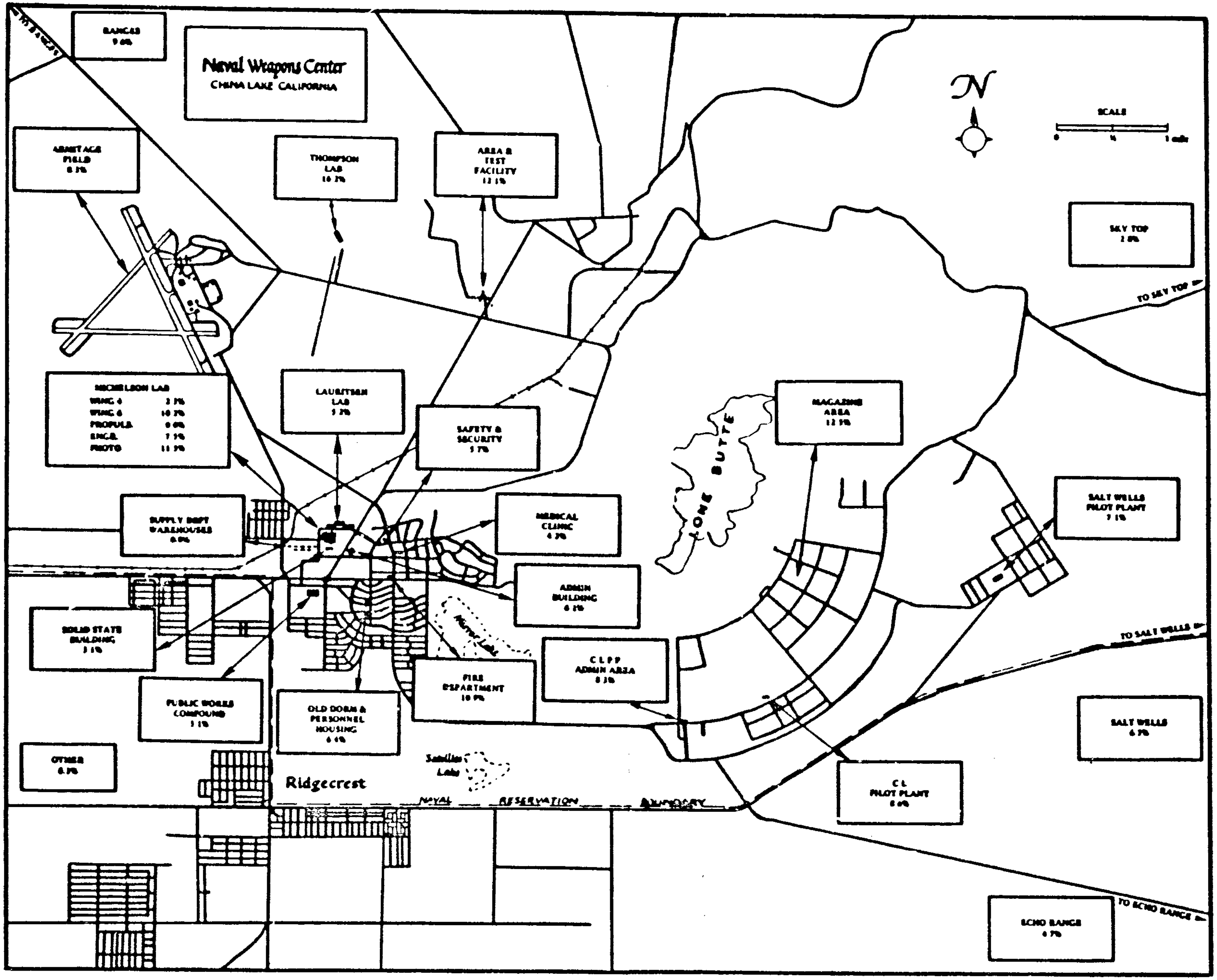


Figure 10. Map of prevalence rates of initial low white

Table 11. Distribution of work codes in Thompson Laboratory, Naval Weapons Center, China Lake, California 1982-83

	Thompson laboratory participants	
Electronic warfare department	No.	Percent
Administration, system sciences, and RF divisions	58	61.1
Microwave development division	25	26.3
EWTES division	1	1.1
All	84	88.5
Other codes	11	11.5
Total	95	100.0

tically significantly lower than the total NWC population (6.1 and 6.6 x 10^3 cells per mm^3, respectively).

3. <u>Persistent low white blood cell counts</u>. Previous sections have dealt only with the results of the first blood count drawn on study participants. If the first count was found to be less than or equal to 4,500 cells per mm^3, the person was asked to return for a second count one month later. If the second count was also less than or equal to 4,500 cells per mm^3, the person was called back one month later for a third count. If the results of all three tests were below this level the person was considered to have a persistent low white blood cell count and was referred to Balboa Naval Hospital, San Diego, California, for an extensive bone marrow evaluation.

A unique aspect of this study is its ability to follow any individual who had been identified as having a white blood cell count less than or equal to 4,500 cells per mm^3 over a three-month period. On the first blood count 7.4 percent of participants had counts $\leq$4,500 cells per mm^3. By the third blood count, 1.2 percent of the population were found to have persistently low white blood cell counts (Figure 11). However, attrition in the second blood draw (N = 19) and third blood draw (N = 12) groups could have led to a substantial underestimate of the number of persistent low white blood cell counts in the population. Smoking may mask depression of WBC counts: only 2 (5.7%) of individuals with chronic low white blood cell counts were smokers.

4. <u>Effects of occupation: two and three blood draws</u>. Prevalence rates of initial white blood cell counts showed the Electronic Warfare Department to be significantly high ($p < 0.05$) (Table 6). A high rate persisted on two consecutive blood counts and was statistically significant (Appendix A Table A4). On three consecutive blood draws, the rate remained high (two and one-half

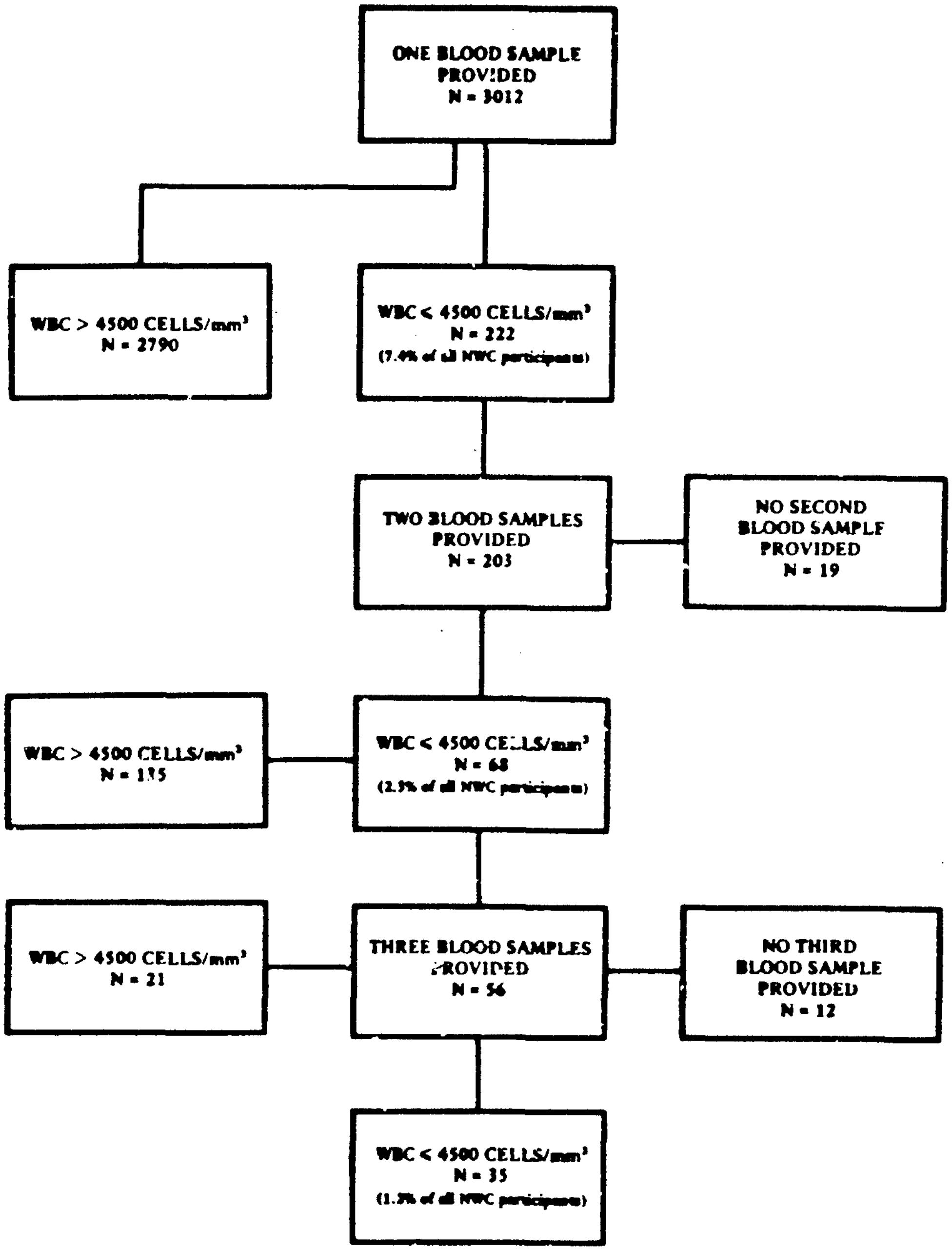


Figure 11. Flow chart of study participants by number of blood samples provided, and number of low white blood cell counts

times the total NWC population) but not statistically significant (Table 12, Figure 12).

5. Effects of work location: two and three blood counts. Prevalence rates of initial low white blood cell counts were significantly high in the Thompson laboratory (Table 10). A high rate persisted on two consecutive white blood cell counts but was not statistically significant (Appendix A Table A5). The rate for three consecutive blood draws also remained high but was not statistically significant (Table 13, Figure 13). The Thompson laboratory had a prevalence rate of 4.1 percent (N = 4), the highest for any location. By comparison the rate for all areas combined was 1.2 percent. Area R and Extension and the Air Facility had the next highest prevalence rates, 3.4 percent and 2.6 percent respectively. While these rates for Area R and Extension and the Air Facility were higher than for the total NWC population, they were not statistically significantly so.

6. Electronic Warfare Department. The Electronic Warfare Department had a smoking-adjusted prevalence rate of initial low white blood cell counts significantly higher than the total NWC population (Table 6). This excess persisted on three consecutive blood draws but the excess was not significant (Table 12, Figure 12). Nearly 90 percent of participants from the Electronic Warfare Department reported working in the Thompson laboratory, a location which was observed to have a significantly high rate of initial low white blood cell counts.

Because of the high prevalence rates of low white blood cell counts, this department was selected for further analysis, including data obtained from the second year of the study. Figure 14 is a flow chart describing the ascertainment of cases in this department throughout the entire study period.

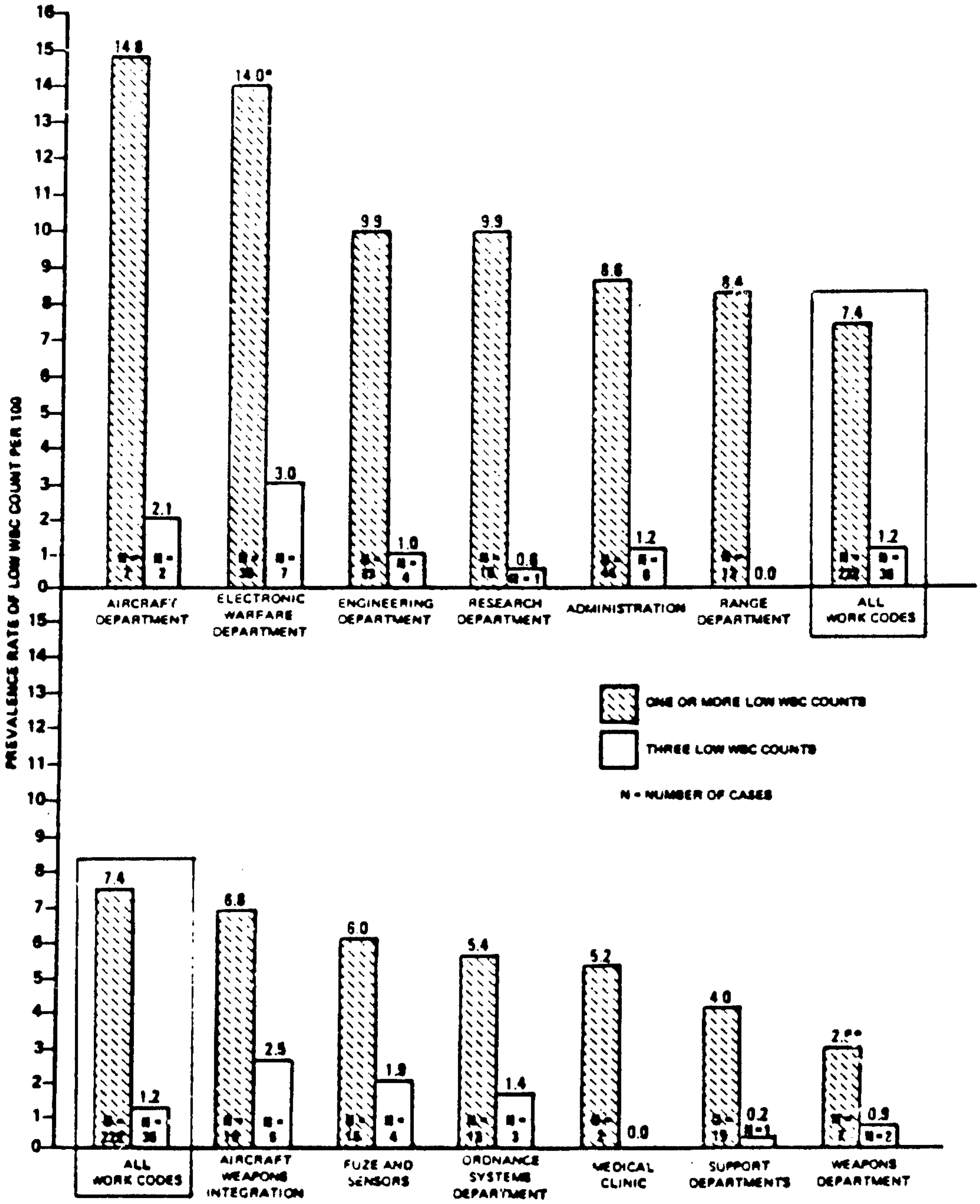
In year one of the study, nine persistent cases (having three or more consecutive low white blood cell counts) were ascertained.

Table 12. Prevalence rate of study subjects having three consecutive low white blood cell counts ($\leq$4,500 cells per mm^3), by grouped work code, Naval Weapons Center, China Lake, California, 1982-83

Grouped work codes	Current smokers: No. of cases	Current smokers: No. of participants	Current smokers: Rate per 100	Current smokers: 95% Confidence limits Lower	Current smokers: 95% Confidence limits Upper	Non-smokers: No. of cases	Non-smokers: No. of participants	Non-smokers: Rate per 100	Non-smokers: 95% Confidence limits Lower	Non-smokers: 95% Confidence limits Upper	Total: No. of cases	Total: No. of participants	Total: Rate per 100	Total: 95% Confidence limits Lower	Total: 95% Confidence limits Upper
1. Administration	0	141	0.0	0.0	--	6	363	1.6	0.3	3.0	6	504	1.2	0.2	2.1
2. Medical clinic	0	16	0.0	0.0	--	0	28	0.0	0.0	--	0	44	0.0	0.0	--
3. Support depts.	0	209	0.0	0.0	--	1	328	0.3*	0.0	0.9	1	537	0.2	0.0	0.6
4. Research dept.	0	32	0.0	0.0	--	1	129	0.8	0.0	2.3	1	161	0.6	0.0	1.8
5. Engineering dept.	0	116	0.0	0.0	--	4	269	1.5	0.0	2.9	4	385	1.0	0.0	2.0
6. Aircraft weapons integ. dept.	0	29	0.0	0.0	--	5	174	2.9	0.4	5.4	5	203	2.5	0.3	4.6
7. Ordnance system dept.	0	59	0.0	0.0	--	3	161	1.9	0.0	3.9	3	220	1.4	0.0	2.9
8. Fuze and sensors	0	31	0.0	0.0	--	4	180	2.2	0.1	4.4	4	211	1.9	0.0	3.7
9. Electronic warfare dept.	0	59	0.0	0.0	--	7	177	4.0	1.1	6.8	7	236	3.0	0.8	5.1
10. Weapons dept.	0	48	0.0	0.0	--	2	179	1.1	0.0	2.7	2	227	0.9	0.0	2.1
11. Aircraft dept.	1	21	4.0	0.1	26.5	1	27	3.7	0.0	10.8	2	48	2.1	0.0	6.1
12. Range dept.	0	62	0.0	0.0	--	0	135	0.0	0.0	--	0	197	0.0	0.0	--
13. Unknown	0	2	0.0	0.0	--	0	2	0.0	0.0	--	0	35+	0.0	0.0	--
Total	1	825	0.1	0.0	0.7	34	2,152	1.6	1.0	2.1	35	3,012	1.2	0.8	1.5

*Significantly low at the $p \leq 0.05$ level.

+Includes 31 with unknown smoking status.



*Significant at the $p \leq .05$ level

Figure 12. Prevalence rates in percent of study subjects with low white blood cell counts on initial blood count, and on three consecutive blood counts, by grouped work code

Table 13. Prevalence rate of study subjects having three consecutive low white blood cell counts ($\leq$4,500 cells per mm^3), by work location, Naval Weapons Center, China Lake, California, 1982-83

	Work location	Current smokers					Non-smokers					Total				
		No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	95% Confidence limits Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	95% Confidence limits Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	95% Confidence limits Upper
1.	Administration bldg.	C	42	0.0	0.0	--	1	88	1.1	0.0	3.4	1	130	0.8	0.0	2.[illegible]
2.	Air facility	1	70	1.4	0.0	4.2	5	152	3.2	0.4	5.9	6	228	2.6	0.6	4.[illegible]
3.	Area R and extension	0	23	0.0	0.0	--	3	66	4.5	0.0	9.6	3	89	3.4	0.0	7.1
4.	CL pilot plant	0	18	0.0	0.0	--	1	39	2.6	0.0	7.5	1	57	1.8	0.0	5.[illegible]
5.	CLPP administration area	0	15	0.0	0.0	--	0	45	0.0	0.0	--	0	60	0.0	0.0	--
6.	CT/sky top area	0	11	0.0	0.0	--	0	25	0.0	0.0	--	0	36	0.0	0.0	--
7.	Echo range	0	23	0.0	0.0	--	0	41	0.0	0.0	--	0	64	0.0	0.0	--
8.	Fire station	0	29	0.0	0.0	--	0	26	0.0	0.0	--	0	55	0.0	0.0	--
9.	Lauritsen laboratory	0	8	0.0	0.0	--	1	66	1.5	0.0	4.5	1	74	1.4	0.0	4.[illegible]
10.	Magazine area	0	5	0.0	0.0	--	0	3	0.0	0.0	--	0	8	0.0	0.0	--
	Michelson laboratory															
11.	Engineering labs	0	23	0.0	0.0	--	0	70	0.0	0.0	--	0	93	0.0	0.0	--
12.	Photography lab	0	7	0.0	0.0	--	0	19	0.0	0.0	--	0	26	0.0	0.0	--
13.	Propulsion lab	0	3	0.0	0.0	--	0	3	0.0	0.0	--	0	6	0.0	0.0	--
14.	Wing 4	0	9	0.0	0.0	--	0	34	0.0	0.0	--	0	43	0.0	0.0	--
15.	Wing 6	0	16	0.0	0.0	--	0	43	0.0	0.0	--	0	59	0.0	0.0	--
16.	Other	1	118	0.8	0.0	2.5	8	411	1.9	0.6	3.3	9	529	1.7	0.6	2.8

Table 13. (Cont'd)

Work location	Current smokers					Non-smokers					Total				
	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	Upper
17. Old dorm, personnel housing	0	50	0.0	0.0	--	2	119	1.7	0.0	4.0	2	169	1.2	0.0	2.8
18. On the road	0	3	0.0	0.0	--	0	8	0.0	0.0	--	0	11	0.0	0.0	--
19. Public works compound	0	25	0.0	0.0	--	0	71	0.0	0.0	--	0	96	0.0	0.0	--
20. Ranges	0	42	0.0	0.0	--	2	89	2.2	0.0	5.3	2	131	1.5	0.0	3.6
21. Safety and security	0	8	0.0	0.0	--	0	27	0.0	0.0	--	0	35	0.0	0.0	--
22. Salt wells pilot plant	0	20	0.0	0.0	--	0	78	0.0	0.0	--	0	98	0.0	0.0	--
23. Supply dept warehouse	0	20	0.0	0.0	--	0	35	0.0	0.0	--	0	55	0.0	0.0	--
24. Solid state building	0	4	0.0	0.0	--	0	28	0.0	0.0	--	0	32	0.0	0.0	--
25. Thompson laboratory	0	15	0.0	0.0	--	4	83	4.8	0.2	9.4	4	98	4.1	0.2	8.0
26. Other areas	0	57	0.0	0.0	--	3	216	1.4	0.0	2.9	3	273	1.1	0.0	2.3
27. Unknown	0	161	0.0	0.0	--	0	261	0.0	0.0	--	3	457*	0.6	0.0	1.4
Total	2	825	0.2	0.0	0.6	3	2,152	0.1	0.0	0.3	35	3,012	1.2	0.8	1.5

*Includes 35 people with unknown smoking status.

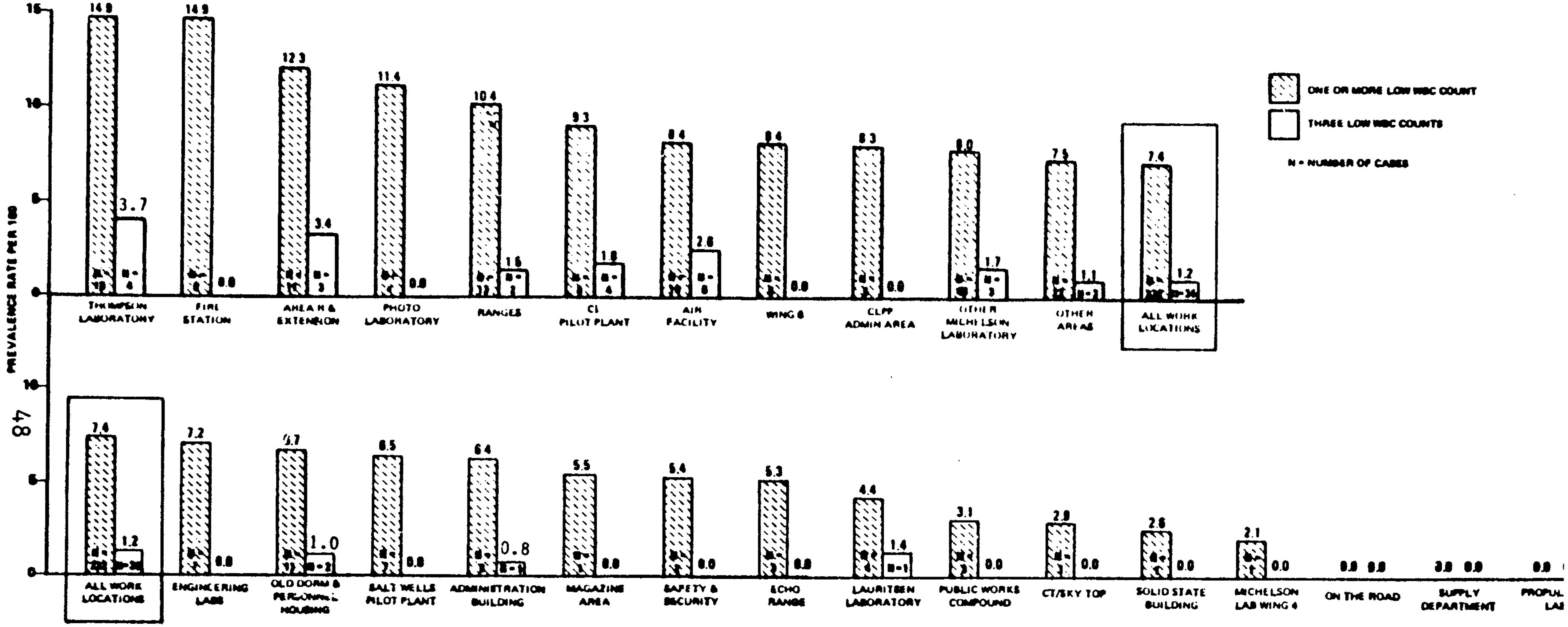


Figure 13. Smoking-adjusted prevalence rate in percent of study subjects with low white blood cell counts on initial blood count, and on three consecutive blood counts, by work location

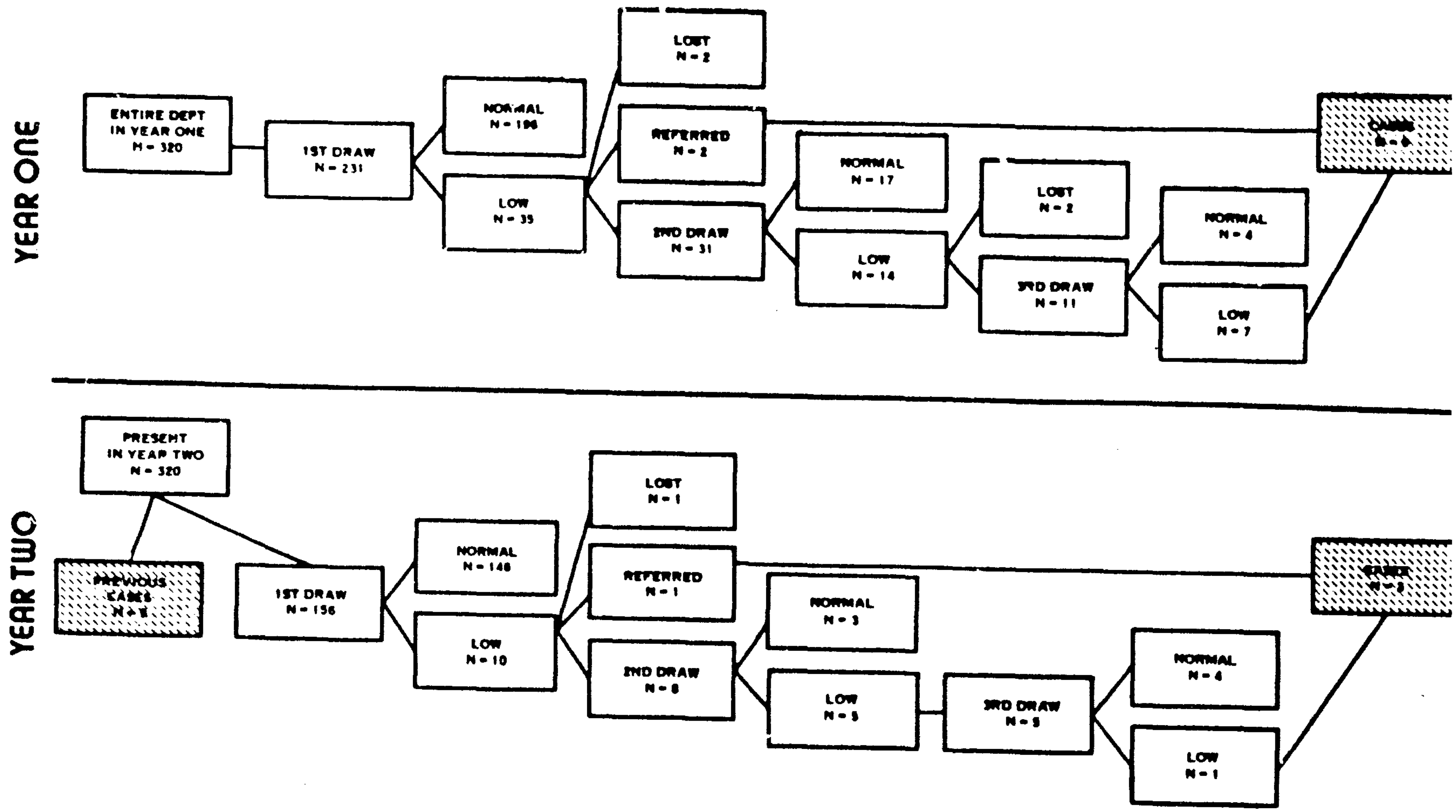


Figure 14. Flow chart showing case ascertainment in the Electronic Warfare Department during the two-year study period

Two of these cases had been identified by routine WBC counting before the study began. The remaining seven cases were ascertained by blood counts which were performed as part of this study. In year two of the study, although many fewer (N = 156) departmental employees chose to participate, two additional persistent cases having three or more consecutive low white blood cell counts were identified.

A detailed record of each participant from the Electronic Warfare Department with at least one low white blood cell count is shown in Appendix A Table A6.

Nearly 90 percent of persons working in Thompson Laboratory reported being employed in the Electronic Warfare Department (Table 11). However, not all members of the Electronic Warfare Department worked in Thompson laboratory. Table 14 and Figure 15 show the prevalence rate of low white blood cell counts by division and work location in the Electronic Warfare Department. The total rate was very similar in persons working in Thompson laboratory (16.7%) or in other locations (14.3%)(Table 14). The Microwave Development Division had the highest rate both in Thompson laboratory (24.0%) and in other locations (33.3%). The Electronic Warfare Threat Evaluation Section had a very low rate. It appeared that occupation was more important than work location in determining these rates.

Section III - The Naval Hospital, San Diego, Study

Physical examinations and blood monitoring have been conducted at the Naval Weapons Center as needed throughout its history. Personnel identified as having potential exposure to hazardous agents, such as trichlorethylene, methylene chloride, benzene, toluene, or asbestos, were selected at the departmental level for physical examinations, blood tests, or other laboratory tests. The frequency and duration of monitoring varied with the amount and duration of potential work exposure.

Table 14. Prevalence rates in percent for low white blood cell counts ($\leq$ 4,500 cells per mm^3), Electronic Warfare Department, by work division and work location, Naval Weapons Center, China Lake, California 1982-83

Division of Electronic Warfare Department	Work location: Thompson Laboratory: No. of participants	Thompson Laboratory: No. with $\leq$ 4,500 cells/mm^3	Thompson Laboratory: Rate	Other: No. of participants	Other: No. with $\leq$ 4,500 cells/mm^3	Other: Rate	All: No. of participants	All: No. with $\leq$ 4,500 cells/mm^3	All: Rate
Administration, system sciences, and radio frequency	58	8	13.8	54	10	18.5	112	18	16.1
Microwave development	25	6	24.0	21	7	33.3	46	13	28.3
Electronic warfare threat environment simulation (EWTES)	1	0	0.0	58	2	3.4	59	2	3.4
Unknown	--	--	--	--	--	--	23	2	8.7
Total	84	14	16.7	133	19	14.3	240	35	14.6

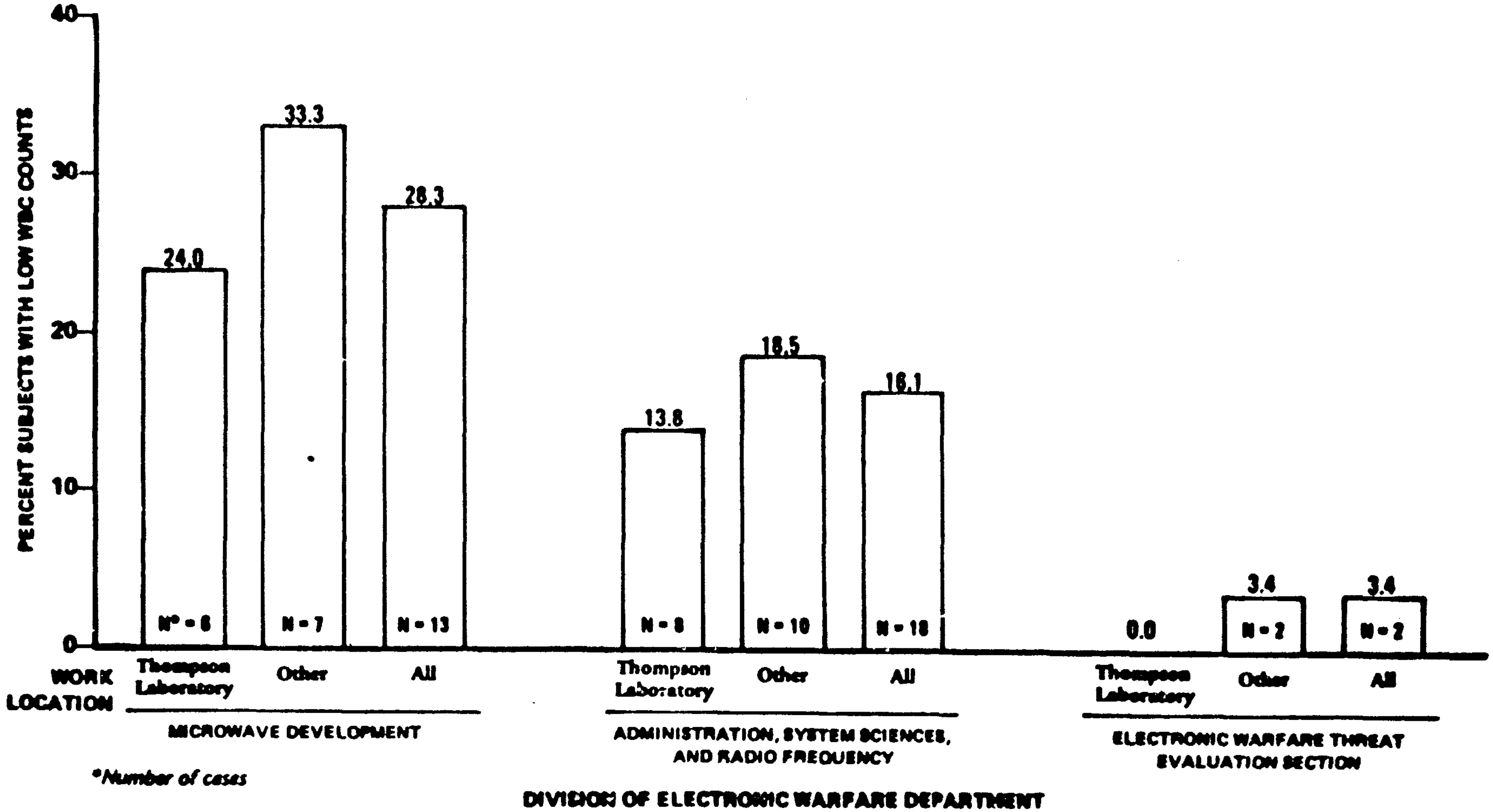


Figure 15. Percent of subjects with low white blood cell counts in the Electronic Warfare Department, by division and work location

One work code, the chemistry division (Code 385), is provided routine blood monitoring every six months, with some individuals having tests more frequently.

A review of the testing log at the Branch Medical Clinic at China Lake in March 1983 indicated that blood monitoring was being conducted on the Photographic Division (Code 345) as well as a number of departments, Engineering (Code 36), Fuze and Sensors (Code 33), Public Works (Code 26), and Ordnance (Code 32). However, the groups being monitored can change on a daily basis.

This monitoring identified 121 individuals determined to have low white blood cell counts during their career at NWC, and who were asked to go to Naval Hospital, San Diego, for examination beginning in May of 1981. Of the 121 asked, 84 were seen at the hospital and 37 were not. Of the 121 identified individuals, 36 did not participate in the main survey and their available history is summarized in Table 15.

Section IV - NWC Designated Exposure Categories

1. Exposure categories. Additional analyses were requested by NWC management following presentation of preliminary results. Their primary concerns were with possible exposure of chemical workers to toxic chemicals and the product line of the Microwave Development Division. The management at NWC felt that in order to address these concerns, exposures could be refined beyond work locations and job title. Therefore, a committee of department heads was formed and four exposure categories were defined as follows:

1A. Chemical workers who frequently work with toxic materials

1B. Chemical workers who infrequently work with toxic materials

2A. Electromagnetic workers whose work involves high power/high voltage/ionizing radiation, and

2B. Electromagnetic workers whose work involves only laboratory RF levels

Table 15. Naval Hospital, San Diego, study referrals who did not participate in the white blood cell count study Naval Weapons Center, China Lake, California, 1982-83

Subject number	Examined at Balboa?	No. of blood samples	No. of low white blood cell counts	Grouped work codes
1	yes	3+	3	Weapons dept.
2	yes	3+	3	Support dept.
3	yes	3+	3	Engineering dept.
4	yes	3+	3	Ordnance systems dept.
5	yes	3+	3	Support dept.
6	yes	3+	3	Weapons dept.
7	yes	3+	3	Range dept.
8	yes	3+	3	Range dept.
9	yes	3+	3	Weapons dept.
10	yes	3+	3	Ordnance dept.
11	yes	3+	3	Unknown
12	yes	3	3	Unknown
13	yes	2	2	Administration
14	yes	1	1	Range dept.
15	yes	Unknown*	Unknown	Range dept.
16	yes	Unknown*	Unknown	Support dept.
17	yes	Unknown*	Unknown	Unknown
18	yes	Unknown*	Unknown	Unknown
19	yes	Unknown*	Unknown	Unknown
20	yes	Unknown*	Unknown	Unknown
21	no	5	5	Engineering dept.
22	no	3	3	Engineering dept.
23	no	1	1	Research dept.
24	no	1	0	Support depts.
25	no	4	4	Aircraft depts.
26	no	Unknown		Research depts.
27	no	Unknown*+	Unknown	Unknown
28	no	Unknown*+	Unknown	Unknown
29	no	Unknown*+	Unknown	Unknown
30	no	Unknown*+	Unknown	Unknown
31	no	Unknown*+	Unknown	Unknown
32	no	Unknown*+	Unknown	Unknown
33	no	Unknown*+	Unknown	Unknown
34	no	Unknown*+	Unknown	Unknown
35	no	Unknown*+	Unknown	Unknown
36	no	Unknown*+	Unknown	Unknown

*Medical record not available at NWC or Balboa Hospital.

+No longer at NWC as of February 1, 1982.

These categories were developed to address the following issues which were raised by the preliminary analyses:

1) Thompson laboratory and the Microwave Development Division were observed to have the highest incidence of low white blood cell counts. Job description and work location in this laboratory were not adequate exposure measures, and more specific evaluation was needed before any conclusions could be drawn between possible exposure to non-ionizing radiation and depressed WBC count.

2) Chemical workers with significant exposures might be buried within broad job descriptions and work location categories, masking effects present in high exposure individuals. More detailed analyses were needed to address this issue.

A listing of the 3,012 participants which included only name and social security number (no information regarding blood results were provided) who participated in the study was reviewed by pertinent managers at NWC to identify employees who might belong in one or more of the above four categories. A total of 408 individuals were selected by NWC management for further statistical analyses (13.5% of original study population).

2. Demographic characteristics. The frequency distribution by age of the 408 NWC-exposure-category subjects is shown in Table 16. Approximately 82 percent were between 25 and 54 years old and about 62 percent were between 35 and 54 years. This age distribution was very similar to that of the total study population of 3,012 NWC participants. Age has little effect on mean WBC counts at NWC; therefore, no adjustment for age was necessary when calculating prevalence rates of low white blood cell counts by these exposure categories.

Ninety-two percent of the individuals were males and eight percent were females, somewhat different from the 70 percent male and 30 percent female in the total study population. However, as

Table 16. Frequency distribution of NWC-exposure-category subjects by age, Naval Weapons Center, China Lake, 1982-83

Age (years)	Number	Percent
15-24	4	1.0
25.34	82	20.1
35-44	122	29.9
45-54	131	32.1
55-64	59	14.5
65+	10	2.4
Total	408	100.0

with age, sex has little effect on mean WBC counts, and no adjustment was performed.

The number and percentages of individuals in each of the four NWC exposure categories is shown in Table 17.

Table 18 shows the distribution of cigarette smoking status for each of the four categories at the time of the blood drawing. Approximately 23 percent were current smokers, and 77 percent were nonsmokers. However, within each of the four categories, current smokers ranged from a low of 16.1 percent in chemical workers who frequently work with toxic materials (category 1A), to a high of 26.6 percent in electromagnetic workers whose work involves high power/high voltage/ionizing radiation (category 2A). Previous results have shown that smoking tends to elevate the WBC count by as much as 2,200 cells per mm^3; therefore, it was necessary to adjust for the effect of smoking when determining prevalence rates of low WBC counts for these four exposure categories.

3. Mean White Blood Cell count. Table 19 shows mean WBC count for the four NWC exposure categories. The lowest mean WBC count (6.26×10^{-3} cells/mm^3) was in category 1A, chemical workers who frequently work with toxic materials, and the highest mean WBC count (7.49×10^{-3} cells/mm^3) was in electromagnetic workers whose work involves high power/high voltage/ionizing radiation (category 2A). Because mean WBC counts are not adjusted for smoking, the differences seen may be due to the proportion of smokers in the different groups. For example, category 1A which has the lowest proportion of smokers also has the lowest mean WBC count, and conversely, category 2A, with the highest proportion of smokers, has the highest mean WBC count.

4. Prevalence of low White Blood Cell counts. Smoking-adjusted prevalence rates (in percent) of low WBC counts were calculated for each of the four NWC exposure categories (Table 20). They range from a low of 1.3 percent for category 2A

Table 17. Number and percent of subjects by NWC exposure categories, Naval Weapons Center, China Lake, 1982-83

NWC exposure category	No.	Percent
1A. Chemical workers who frequently work with toxic materials	89	21.8
1B. Chemical workers who infrequently work with toxic materials	102	25.0
2A. Electromagnetic workers whose work involves high power/high voltage/ionizing radiation	79	19.4
2B. Electronic workers whose work involves only laboratory RF levels	138	33.8
Total	408	100.0

Table 18. Percent distribution of NWC-exposure-category subjects by cigarette smoking status, Naval Weapons Center, China Lake, 1982-83

NWC exposure category	Smoking Status Current %	Nonsmoker %
1A. Chemical workers who frequently work work with toxic materials	16.1	83.9
1B. Chemical workers who infrequently work with toxic materials	23.8	76.2
2A. Electromagnetic workers whose work involves high power/high voltage/ ionizing radiation	26.6	73.4
2B. Electronic workers whose work involves only laboratory RF levels	24.8	75.2
Total	22.8	77.2

Table 19. Mean white blood cell count x $10^{-3}mm^{3}$ by NWC exposure category, Naval Weapons Center, China Lake, 1982-83

NWC exposure category	No.	Mean WBC count x$10^{-3}mm^{3}$
1A. Chemical workers who frequently work with toxic materials	89	6.26
1B. Chemical workers who infrequently work with toxic materials	102	6.85
2A. Electromagnetic workers whose work involves high power/high voltage/ionizing radiation	79	7.49
2B. Electronic workers whose work involves only laboratory RF levels	138	7.06
Total	408	6.92

Table 20. Crude and smoking-adjusted prevalence rates in percent of low white blood cell counts, by NWC exposure category, and total NWC population, Naval Weapons Center, China Lake, 1982-83

NWC exposure category	Number of Subjects with LWBCC	Pop.	Crude rate	Smoking Adjusted rate	95% C.I.
1A. Chemical workers who frequently work with toxic materials	6	89	6.7	5.8	0.6, 11.1
1B. Chemical workers who infrequently work with toxic materials	9	102	8.8	8.6	1.5, 15.7
2A. Electromagnetic workers whose work involves high power/high voltage/ionizing radiation	1	79	1.3	1.3	0.0, 4.1*
2B. Electromagnetic workers whose work involves only laboratory RF levels	11	138	8.0	7.8	2.1, 13.51
Total	27	408	6.6	6.4	3.4, 9.3
Total NWC population	222	3,012	7.4	7.4	6.2, 8.5

*Significant at the $p < 0.05$ level when compared to the total NWC population.

(Electromagnetic workers whose work involves high power/high voltage/ionizing radiation) to a high of 8.6 percent for category 1B (Chemical workers who work infrequently with toxic materials). The smoking-adjusted rate in category 2A is approximately 5.7 times lower than the corresponding rate for the total NWC population. This finding was statistically significant ($p < 0.05$) before and after adjustment for smoking.

Approximately 30 percent of those individuals from category 2A reported working in the EWTES division of the Electronic Warfare Department (not shown), a division which was found to have a statistically significant low WBC count (Table 7). In addition, 37 percent (N = 81) of the 217 individuals identified by NWC managers to be at risk for potential exposure to either high power/high voltage/ionizing radiation or laboratory levels of RF (category 2A & 2B) reported working in one of the three divisions of the Electronic Warfare Department. Figure 16 shows the paradoxical finding of both a high rate of low WBC counts (14.3%) in the Microwave Development Division and a low rate of low WBC counts (2.7%) in the EWTES Division of the Electronic Warfare Department. Although somewhat lower, these prevalence rates for low WBC counts parallel those shown in Figure 9 (percent of subjects in the Electronic Warfare Department with low white blood cell counts). However, the 81 individuals mentioned above are essentially a subsample of the original 236 individuals from the Electronic Warfare Department; therefore, these findings might be expected.

5. Effects of work location. Seventy-two percent of the 408 NWC-exposure-category subjects reported working in 12 of 26 possible work locations as shown in Table 21. The work location is self-reported, and many participants either listed more than one location or misinterpreted the question and listed their work code rather than their work location. Consequently, 28% of the participants had missing data for this variable. Table 21 shows

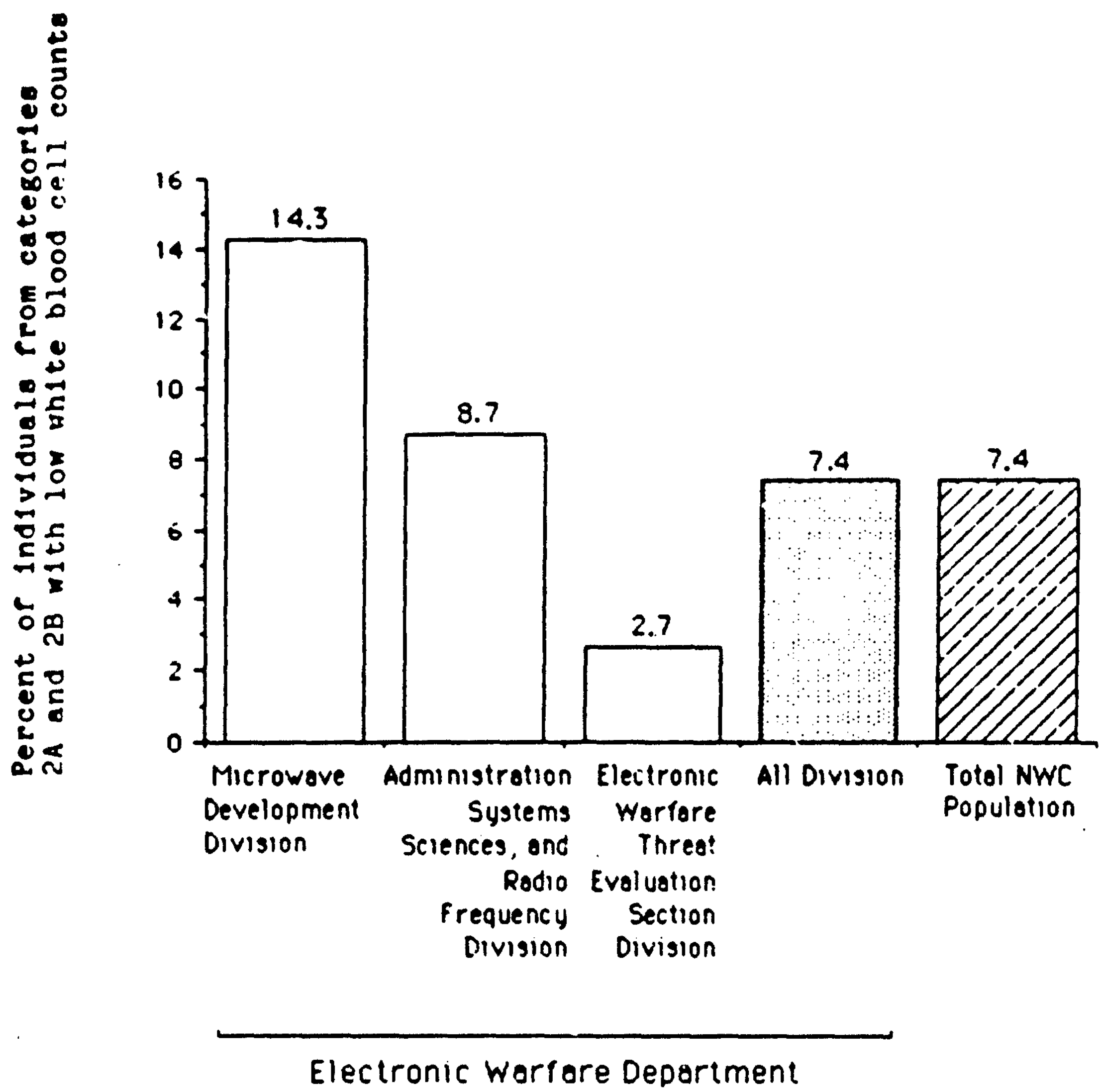


Figure 16. Percent of low white blood cell counts in individuals from NWC-categories 2A and 2B who also reported working in one of the three divisions at the Electronic Warfare Department

Table 21. Prevalence rates in percent of low white blood cell counts in NWC exposure category subjects by work location, Naval Weapons Center, China Lake, 1982-83

Work location	#Cases	Pop.	Rate %	95% Conf. Limits Lower	Upper
Michelson Eng. Lab	2	10	20.0	0.0,	44.8
Area R & Extension	2	11	18.2	0.0,	41.0
Thompson Lab	4	23	17.4	1.9,	32.9
Air Facility	3	19	15.8	0.0,	32.2
Michelson Lab Wing 6	4	27	14.8	1.4,	28.2
Old Dorm Housing	1	10	10.0	0.0,	28.6
CT Sky Top Area	1	13	7.7	0.0,	22.2
Michelson Lab Wing 4	1	14	7.1	0.0,	20.6
Salt Wells Pilot Area	2	50	4.0	0.0,	9.4
Ranges	2	51	3.9	0.0,	9.2
Michelson other	1	28	3.6	0.0,	10.4
ECHO Range	1	37	2.7	0.0,	7.9
Unknown	3	115	2.6	0.0,	5.5
Total	27	408	6.6	4.2,	9.0

Michelson Engineering Laboratory, Area R & Extension, and Thompson Laboratory to have the highest prevalence rates of low WBC counts. This is consistent with the finding for the total NWC population that two of these work locations (Thompson Lab and Area R & Extension) have the highest prevalence rates of low WBC count. However, the rates based on 408 individuals were not statistically significantly different from the rate for the total NWC population rate. The very small number of cases in each area, however, makes statistical determination of observed differences unlikely.

6. Comparison with total NWC population. Distributions of WBC counts for the four NWC-exposure-categories plotted in conjunction with comparison groups drawn from the entire NWC population were done at the request of NWC management. Figures 17-20 show the results of these comparisons.

There does not appear to be any strikingly unusual distributions of WBC counts in any of the four NWC exposure categories given the random variation one would expect from samples of these sizes.

Figure 17 shows a slight possible shift to the left for nonsmoking chemical workers with frequent potential exposures.

Figure 19 shows the distribution of WBC counts for nonsmoking electromagnetic workers involved with high power/high voltage/ionizing radiation may have a slight shift to the right of the baseline WBC distribution.

7. Electronic Warfare Department. As a result of the finding of both a high and low rate of low WBC counts in the Electronic Warfare Department, this department was analyzed in more detail. Figures 21-23 show the frequency distribution of WBC counts for nonsmokers in each of the three divisions of the Electronic Warfare Department, plotted with all other nonsmoking NWC personnel (N = 2145). The frequency distribution of WBC counts for the Microwave Development Division is clearly shifted to the left of

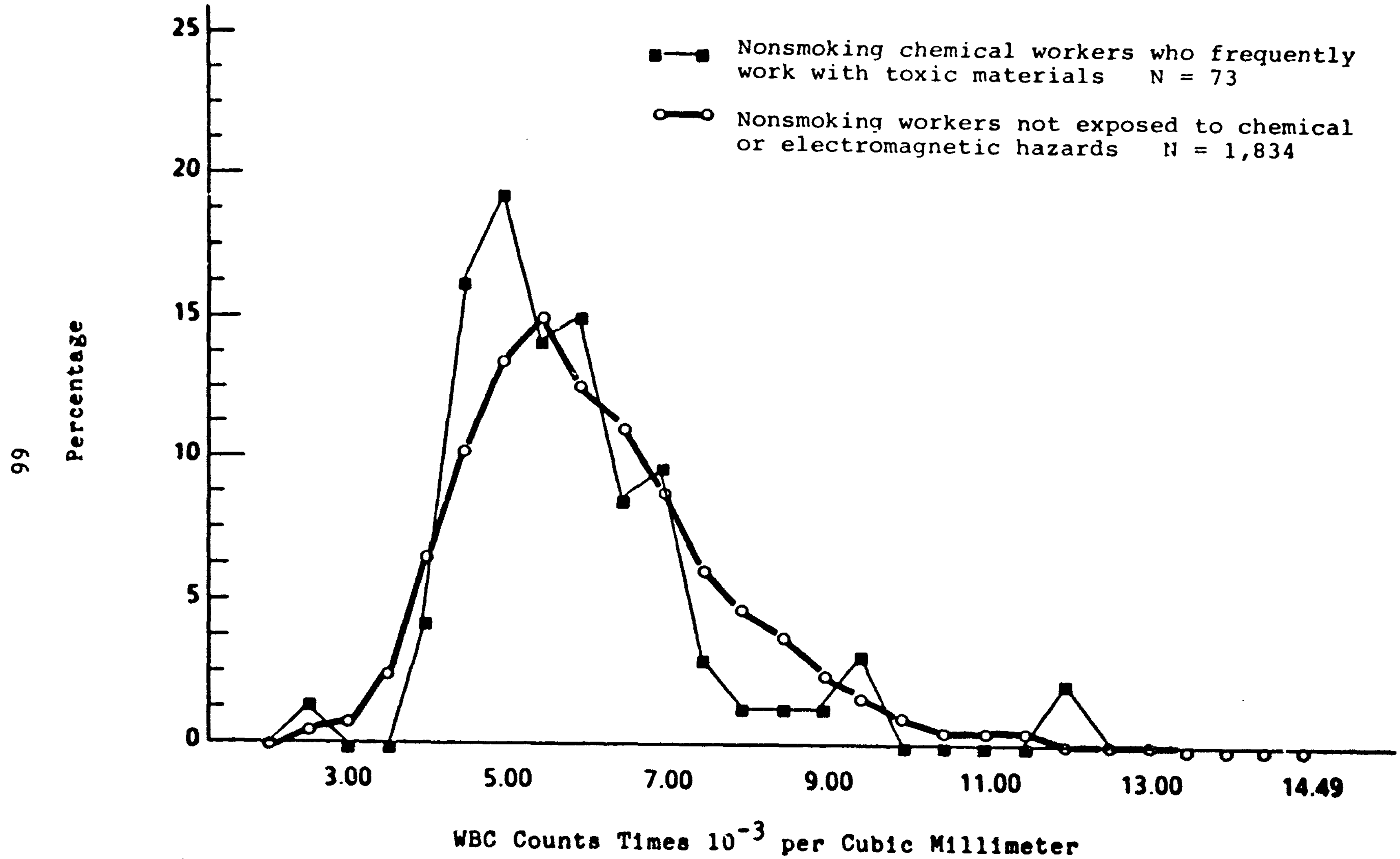


Figure 17. Distribution of white blood cell counts for nonsmokers with frequent exposure to toxic chemicals

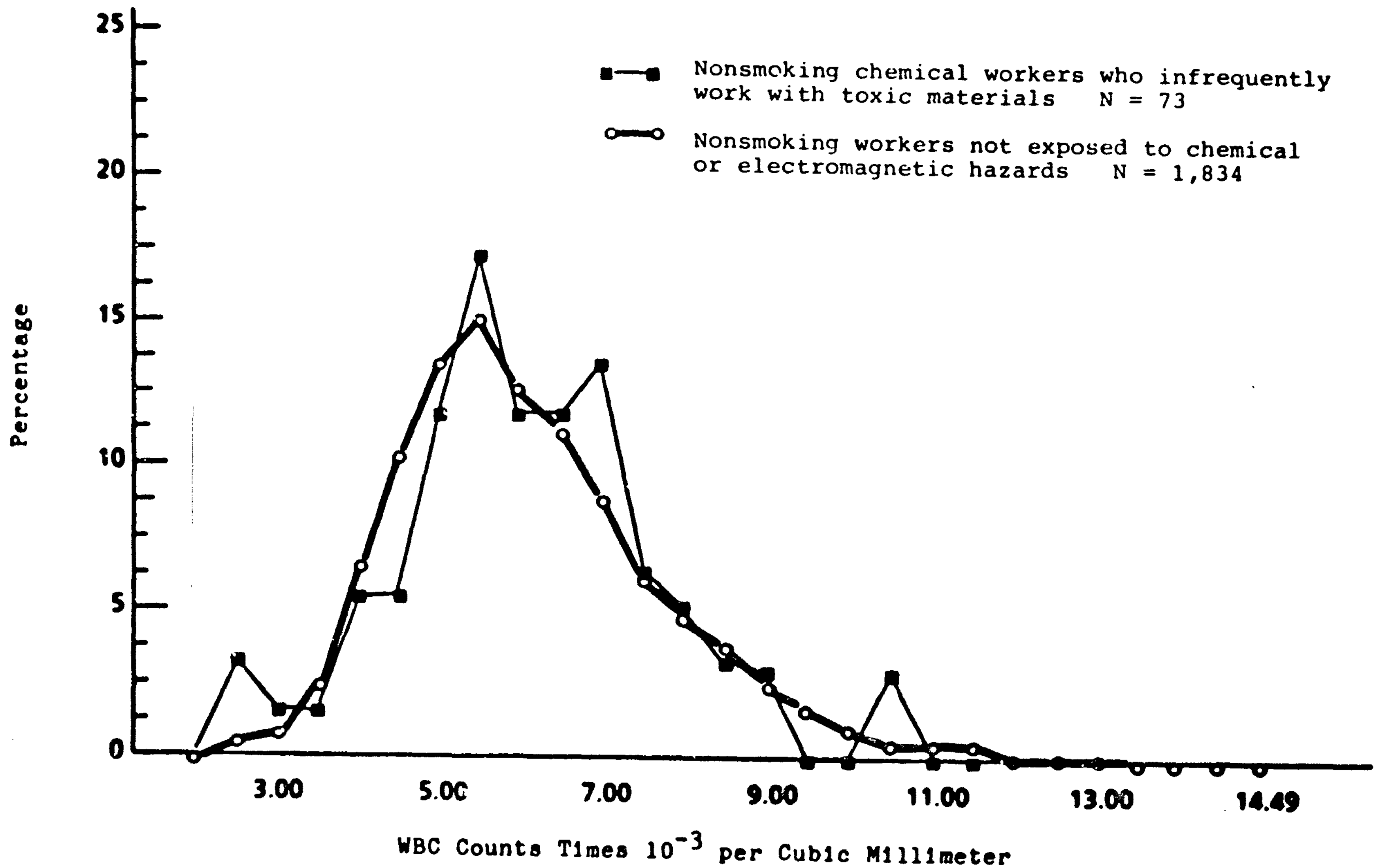


Figure 18. Distribution of white blood cell counts for nonsmokers with infrequent exposure to chemical or electromagnetic radiation

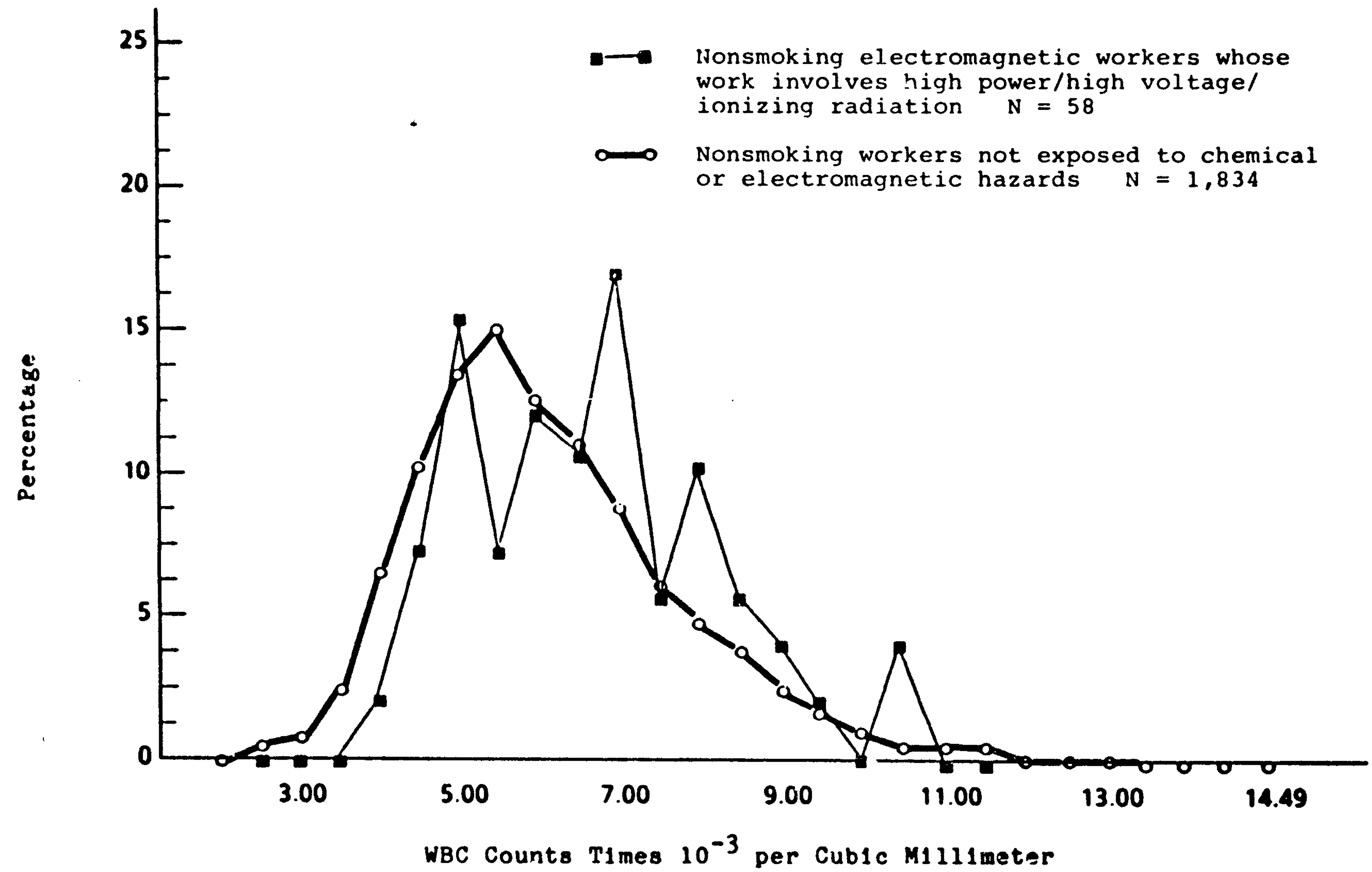


Figure 19. Distribution of white blood cell counts for nonsmokers with exposure to high power/high voltage/ionizing radiation

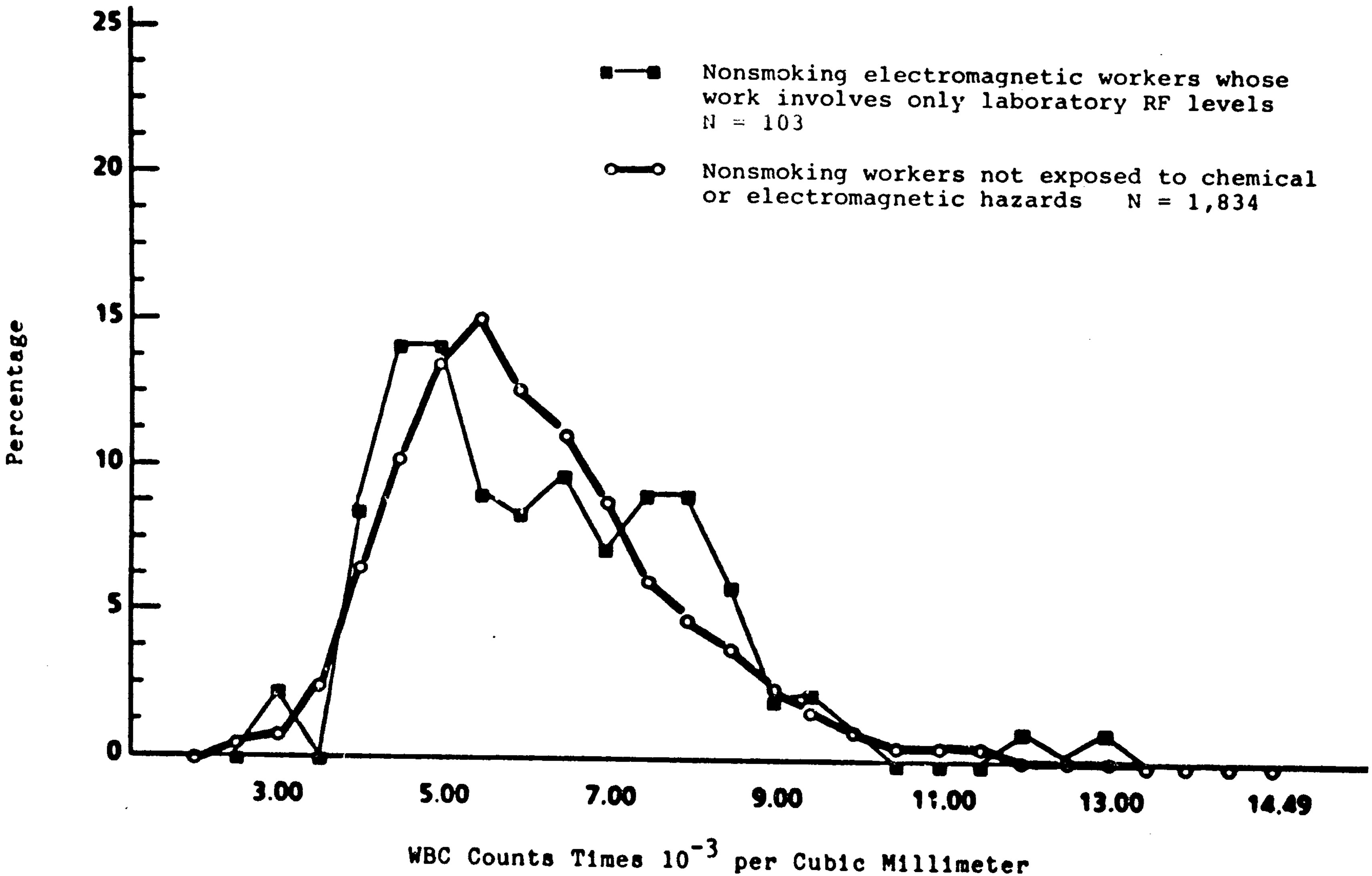


Figure 20. Distribution of white blood cell counts for nonsmokers with exposure to laboratory levels of electromagnetic radiation

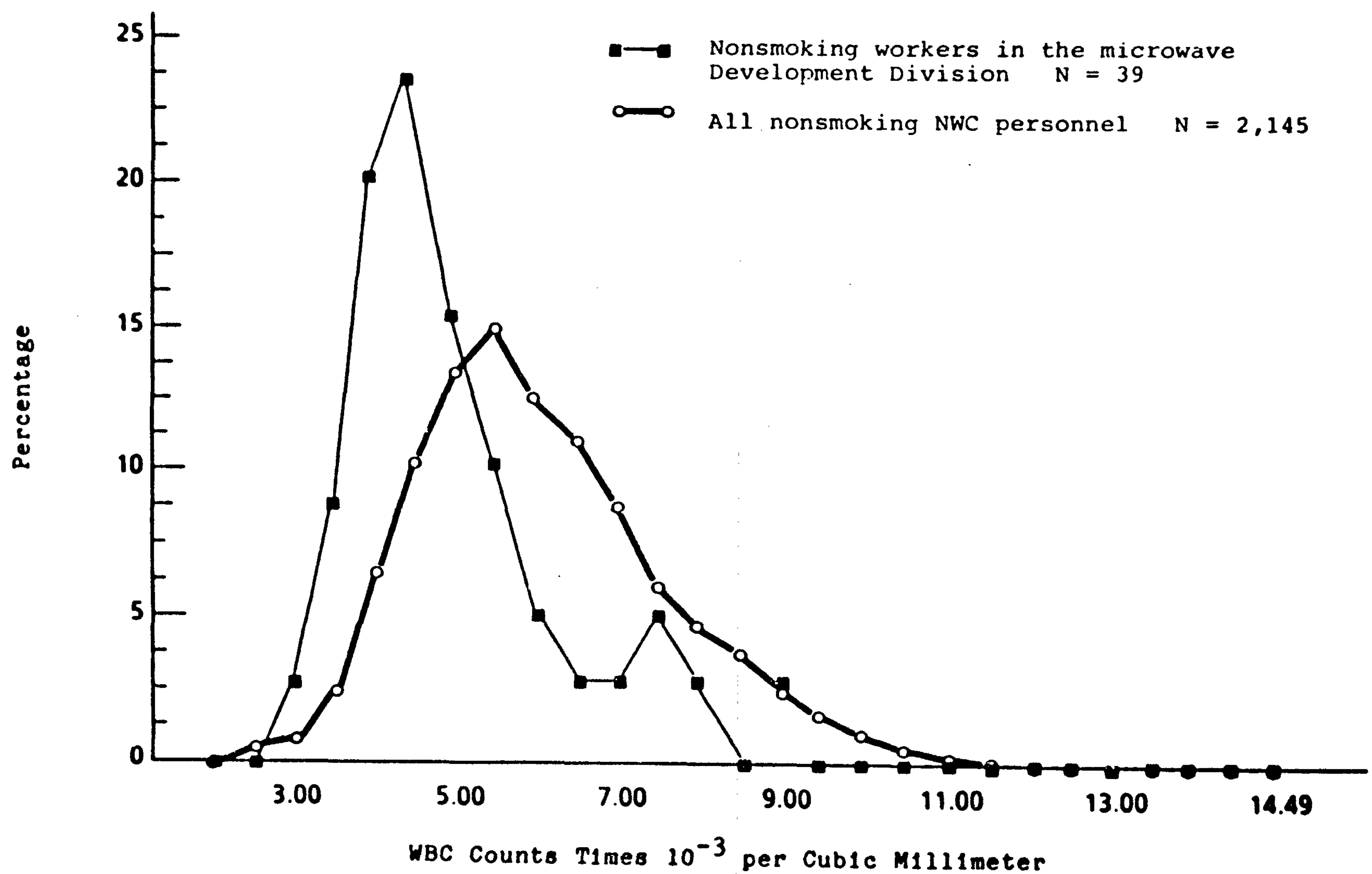


Figure 21. Distribution of white blood cell counts in percent for nonsmoking workers in the Microwave Development Division

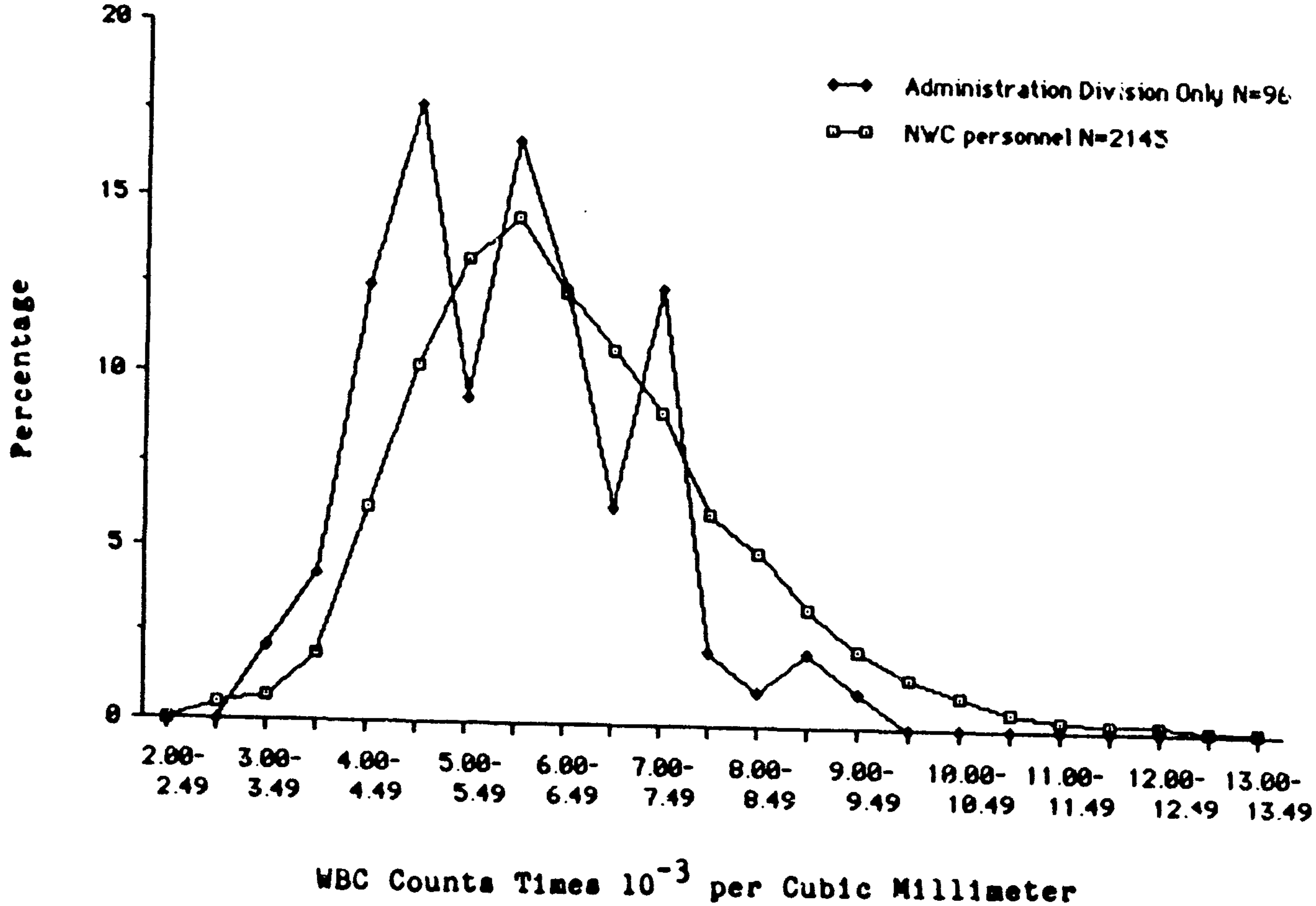


Figure 22. Distribution of white blood cell counts in percent for nonsmoking workers in the Administration Division

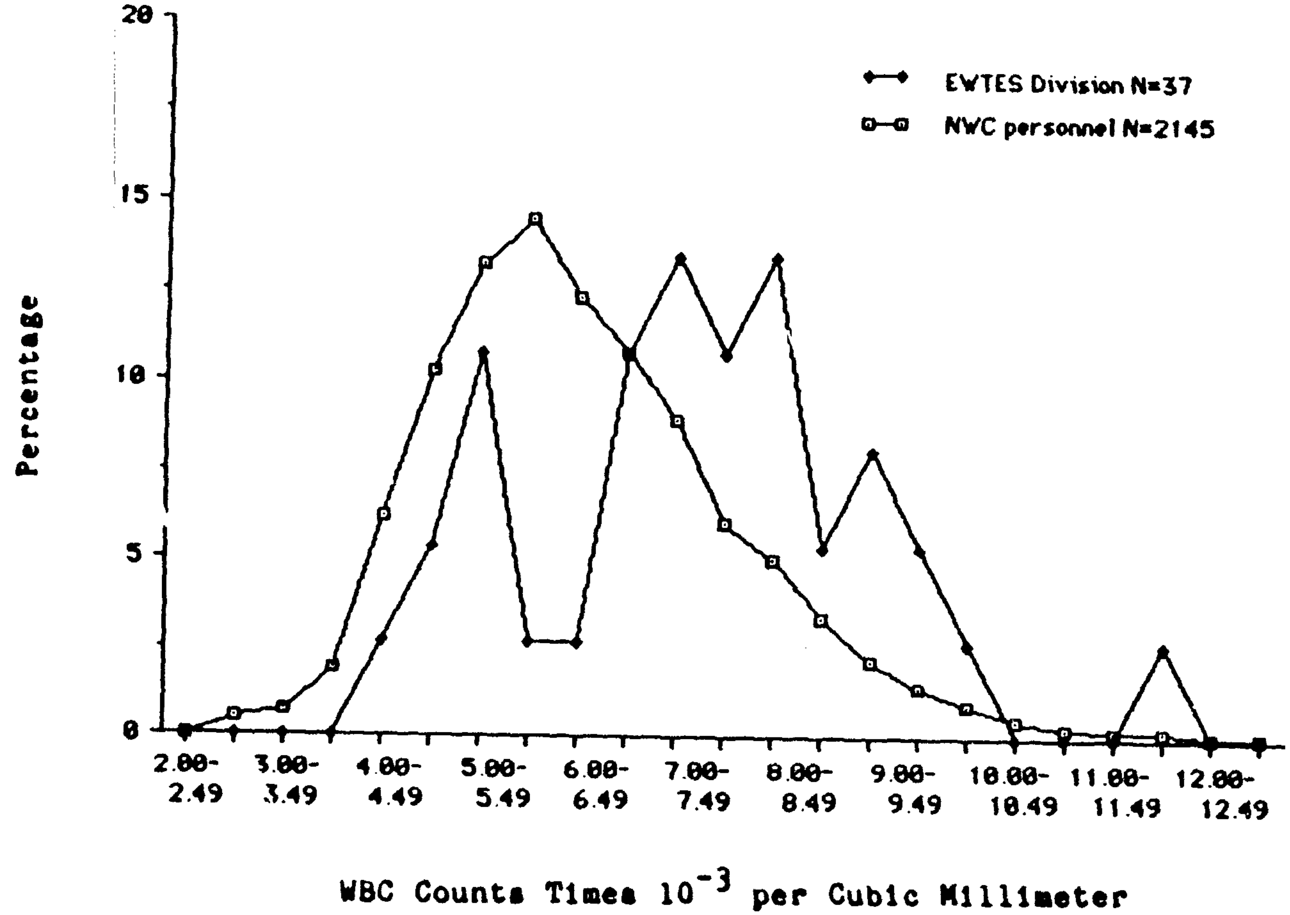


Figure 23. Distribution of white blood cell counts in percent for nonsmoking worker in EWTES Division

the baseline distribution (Figure 21). Table 7 gives the smoking-adjusted prevalence rate for low WBC counts for the three divisions of the Electronic Warfare Department along with 95 percent confidence intervals. Only the Microwave Development Division has a statistically significantly higher prevalence rate ($p < .05$) of low WBC counts after adjustment for smoking when compared to the total NWC population.

NWC management asked the Department of Statistics at Stanford University to perform an independent analysis to assess the statistical difference between the data for the nonsmokers from the Microwave Development Division and the nonsmokers for the rest of the Naval Weapons Center. Their conclusions support the findings that the WBC counts for nonsmoking employees in the Microwave division are lower by between 700 and 1500 cells per mm^{-3} than those of other nonsmoking employees at NWC, and that the difference was very unlikely to have arisen by chance alone. Their complete report is provided in Appendix C.

Discussion

Section I - Demographic Characteristics and Comparison with the U.S. Population

1. Demographic characteristics. The Naval Weapons Center population is predominantly a middle-aged white population which is 70 percent male. The population is relatively stable; nearly 70 percent of participants in the present study had been employed at NWC for five or more years. A smaller proportion of NWC employees currently smoke than members of the general population of the United States. Only about one-quarter of NWC employees smoke cigarettes as compared to approximately one-third of the U.S. adult population (8).

2. Effects of demographic characteristics. No major effect of age on mean white blood cell count (in men ages 20-60) has been reported in previous studies (9, 10, 11, 12) and was not observed in the present study (Table 4). There were no differences in white blood cell counts according to sex in this study (not shown), although other studies have reported a decline in WBC counts in post-menopausal women (9) and an increase in WBC counts among women taking oral contraceptives (13, 14).

If a long-term exposure to some agent was necessary to produce a depressed WBC count, NWC employees might be expected to have mean WBC counts which declined with increasing duration of employment. No such association was observed, however, in the present study (Figures 4 and 5).

3. Effects of cigarette smoking. Current cigarette smoking has a very important influence on mean white blood cell counts (Table 5), as expected based on the results of previous studies (10, 12, 15). The impact of cigarette smoking on mean WBC count was noticeably greater for the NWC population than for the population which participated in the U.S. Health and Nutrition Examination Survey (HANES) (Figure 6) (6).

At NWC the difference in mean WBC between never-smokers (6,200 cells per mm^3) and current smokers (8,400 cells per mm^3) was approximately 2,200 cells per mm^3. While differences of this magnitude were not observed in the HANES, other studies report similar differences in average WBC counts in smokers and non-smokers (10, 12, 16).

In a study of 1,000 clinic patients in the Southern Califorria Permanente Medical Group, mean WBC counts were approximately 2,400 cells per mm^3 greater in male smokers ages 40 to 49 (9,200 cells per mm^3) than in non-smokers in the same age-sex group (6,800 cells per mm^3).

The effect of smoking on WBC counts was present in both sexes in the Southern California Permanente Medical Group Study (10), and in the present study. In a study of 86,488 ambulatory patients in the Northern California Permanente Medical Group who received blood tests during 1964 to 1968, total WBC counts were higher among current smokers in every race and sex category (12). The difference in WBC counts between current smokers and nonsmokers in the study was 1,200 cells/mm^3 in white males and 1,000 cells/mm^3 in white females (12). The Northern California Permanente Medical Group Study also compared WBC counts in two groups of smokers, one with evidence of chronic bronchitis, and one without evidence of this disease; both groups were compared with a group of nonsmokers (12). The differences in WBC counts in male smokers 40-49 years old with chronic bronchitis, for example, was approximately 9,100 cells/mm^3. The mean WBC counts in male smokers the same age without chronic bronchitis was approximately 8,400 cells/mm^3, and the mean WBC counts in a corresponding group of nonsmokers was 7,100 cells/mm^3(12).

A French study of the effect of tobacco smoking on WBC counts in 4,264 men aged 46-52 showed a mean WBC counts of approximately 6,550 cells/mm^3 in current smokers compared to 5,700 cells/mm^3 in nonsmokers ($p \leq 0.01$) (16). There was a dose-response relationship ($p \leq 0.05$) between quantity of tobacco smoked per day and WBC counts and smokers who inhaled had significantly ($p < 0.001$) higher WBC counts than those who did not (16). This study also analyzed the effect of chronic bronchitis in smokers on WBC counts and reported that presence or absence of this condition did not fully explain the impact of smoking on WBC count (16). It appears from both the Northern California Permanente Medical Group Study (12) and the French study (16) that chronic bronchitis does not fully explain the effect of smoking on WBC counts. One or more of over 1,150 different chemicals present in tobacco smoke (12) could account for the increase in WBC counts either through direct antigenic stimulation or by affecting any stage of leukocyte production or removal.

In the present study, cigarette smoking produced both a major displacement in the mean WBC count and a flattening of the shape of the curve of the distribution of the WBC count (Figure 2). It is possible that the flattening of the curve is due to variations in number of cigarettes smoked per day within the category of current smokers.

4. Comparison of mean WBC counts with the National Health and Nutrition Examination Survey. Mean WBC counts for current smokers at NWC were nearly identical with those observed in the HANES, i.e., approximately 8,400 cells per mm^3 at NWC and 8,300 cells per mm^3 in the HANES (Figure 6). Mean WBC counts for former smokers and never smokers at NWC were approximately 800 to 1,000 WBC cells per mm^3 lower than those observed for their demographic counterparts in the HANES (Figure 6).

There are several possible explanations for the lower overall WBC counts for the non-smokers at NWC. The NWC is located in a high desert environment which supports only limited vegetation, minimizing the concentration of pollen and other airborne antigens. It is distant from industrial sources of air pollutants and has a much lower burden of vehicular airborne pollutant emissions than other areas that were included in the HANES sample. It has a stable population with little inward migration and few transient visitors compared to urban areas. A possible consequence of the ecological and cultural characteristics of NWC and the surrounding Ridgecrest community is reduced exposure to the numerous antigens (both microbial and non-microbial) present in the heavily urban United States population. Although detailed studies of the effect of desert environments on WBC counts have not been reported to our knowledge, the possibility must be considered that the shift of WBC counts toward the lower end of the normal range observed in NWC non-smokers might be a result of the specialized ecology of the Ridgecrest community.

Consistent with this explanation was the finding that smokers at NWC had mean WBC counts that were nearly identical with the HANES population. It appears, therefore, that smokers at NWC may be able to mount a fully normal immune response as evidenced by an elevation of WBC count when exposed to cigarette smoke.

Section II - Questionnaire Obtained Exposure Categories

1. Effects of occupation. The Electronic Warfare Department experienced both crude and smoking adjusted prevalence rates of low WBC counts which were nearly double that of the total NWC population (Table 6). These differences were significant at the $p \leq 0.05$ level. The Electronic Warfare Department includes Administration (which is made up of the Department staff and the HARM Program Office), the Microwave Development Division, System Science Division, Radio Frequency Division, and the Electronic Warfare Threat Environment Simulation (EWTES). When these divisions were separated, they had markedly differing smoking-adjusted prevalence rates for low WBC counts of 24.8 percent, 14.8 percent and 3.9 percent, respectively (Table 7).

The smoking-adjusted rate was also elevated in the Aircraft Department, a much smaller department, but the findings did not achieve statistical significance. Non-significant elevations of prevalence rates were also observed in the Research and Engineering Departments. The prevalence rates in the Support Department and the Weapons Department were significantly lower than in the total NWC population.

Because this study contained a large number of statistical comparisons, the possibility exists that significantly high or low results could emerge due to chance alone (5). Therefore, the findings concerning occupation and work location must be regarded with caution appropriate to the statistical methodology. Persistent low WBC counts may be more diagnostic of a true harmful exposure. The design of the present study called for repeated WBC counts for all subjects of $\leq 4,500$ cells per mm^3. If the WBC count remained this low on the repeated WBC count, a third count was obtained.

The Electronic Warfare Department experienced a significantly ($p < 0.05$) elevated prevalence rate of subjects having two consecutive low white blood cell counts (Appendix A Table A4) and the highest, but non-significant, elevated prevalence rate of subjects having three consecutive low WBC counts of all grouped work codes at NWC (Table 12). No other grouped work code attained a statistically significant high prevalence rate on two or three consecutive WBC counts.

The Electronic Warfare Department was subdivided into three divisions for more detailed analysis. This analysis revealed a significantly lower ($p \leq 0.05$) mean WBC count in the Microwave Development Division than any other division and than the total NWC population. A significantly higher mean WBC count was observed in the EWTES Division than in any other division and the total NWC population. This implies the possibility of different exposures within the Electronic Warfare Department.

According to the Industrial Hygiene Department at NWC, employees in the Microwave Development Division may be routinely exposed to low levels of microwave radiation, although their exposures are probably less than members of the EWTES Division.

A review of the medical literature yielded no systematic studies in humans of effects of microwave radiation on WBC counts. Several studies of the impact of microwave radiation on other outcomes were located, however. Robinette, Silverman, and Jablon (17) investigated the effects of occupational exposure to radar in 20,000 male enlisted U.S. Naval personnel involved in electronic equipment repair and 20,000 controls. They detected a non-significant increase (age-standardized mortality ratio = 1.6) for diseases of the lymphatic and hematopoetic system among enlisted personnel presumed to have had high exposure levels based on occupation as compared to those who had little opportunity for exposure. This study did not, however, report on the effect of microwave exposure on white blood cell counts since the design of the study did not allow concurrent physiologic measurements.

Lilienfeld, et al. evaluated the health status of persons exposed to microwave irradiation at the U.S. Embassy in Moscow (18). Exposure of embassy personnel to microwaves was at very low levels. The Lilienfeld study did not reveal important differences in indices of health status between exposed and unexposed personnel; however, it did not include detailed analyses of WBC counts.

Depression of WBC counts has been shown to occur in animals in response to microwave irradiation. The effect of the microwave exposure appears to be transitory (19). In a Czechoslovakian study, 20 male rats were irradiated at a power density of 24.4 microwatts/cm^2 for seven weeks, five days a week, four hours a day. During the second half of the irradiation period, experimental animals had significantly lower ($p \leq 0.01$) mean numbers of leukocytes and lymphocytes than the control group. Six weeks after irradiation, leukocyte levels in the experimental group were still significantly lower than those of the control group but returned to the normal range ten weeks following irradiation. Lymphocyte counts in the experimental group returned to within the normal range three weeks following irradiation (19). A possible mechanism proposed to explain the effects of microwaves on hematopoetic tissue is the acceleration of lipid peroxication, an effect which has been reported to occur in vitro (20). In living systems, such an effect could alter the integrity of the cellular membrane, possibly affecting hematopoetic tissue to a greater extent due to its central location in bone marrow.

2. Effects of work location. Prevalence rates of low WBC counts are more closely related to occupation within the Electronic Warfare Department than to work location (Table 14, Figure 15). This strongly suggests that it is the nature of the work

performed rather than the general physical environment which affects WBC counts.

Section III - The Naval Hospital, San Diego, Study

Ongoing routine examinations of employees at NWC preceding the present study identified 36 employees at NWC who were referred for intensive hematological study at the Naval Hospital, San Diego, but who did not participate in the white blood cell count survey. The grouped work codes of these subjects are shown in Table 15. The predominant source of referrals outside the present study to Naval Hospital was the Range Department (4 referrals), followed by the Engineering, Weapons, and Support Departments (3 referrals each), Ordnance and Research Departments (2 referrals each), and Aircraft and Administration Departments (one referral each).

Section IV - NWC Staff Designated Exposure Categories

Additional analyses were performed on a subset of the total NWC population. Four exposure groupings were developed by NWC line managers (Table 19). Two of the groups consisted of employees identified as having high potential for exposure to either chemical and/or electromagnetic radiation. The other two groups, for comparative purposes, were identified as having lower exposures to these agents.

The smoking-adjusted prevalence rate in percent of low WBC counts ranged from a statistically significant low of 1.3 percent in category 2A, electromagnetic workers whose work involves high power/high voltage/ionizing radiation, to a high of 8.6 percent in category 1B, chemical workers who work infrequently with toxic materials (Table 20).

The prevalence rate of low WBC count for all four NWC-exposure-categories combined was 6.4 percent which is close to the prevalence rate of 7.4 percent seen for the entire NWC population. These categories did not serve to identify any particular group at NWC as having a notably high prevalence rate of low WBC counts, although it did identify a group (Category 2A, electromagnetic worker whose work involves high power/high voltage/ionizing radiation) as having a statistically significant low prevalence rate of low WBC counts.

Conclusions

Several conclusions regarding the occurrence of low WBC counts at the Naval Weapons Center can be drawn from this study. They include:

1. There is no apparen overall environmental exposure affecting all NWC employees. A wide range of prevalence rates by work code (range 3.1% in the Weapons Department to 14.6% in the Electronic Warfare Department) was observed. Duration of employment at NWC also was not a factor affecting WBC counts supporting the conclusion of no general effect.
2. The mean WBC count of persons who have never smoked at NWC is lower. but not importantly so, than the mean WBC count of persons who have never smoked in the general U.S. population (6,200 vs 7,200 cells per mm^3). This difference is within normal limits and may be attributable to less antigenic stimulation in the high desert rural environment of NWC. This conclusion is supported by the observation that mean WBC counts in smokers at NWC were nearly identical to the mean for smokers in a sample of the U.S. population (8,400 vs. 8,300 cells per mm^3), indicating that NWC employees experience the same increase in WBC count as the general population when exposed to cigarette smoke (a possible form of antigenic stimulation).

3. The Electronic Warfare Department had more cases of low WBC counts than would have been expected based on the experience of the entire NWC workforce. The prevalence rate of low WBC counts in this department (14.6%) was significantly higher than in the total NWC population (7.4%). This department also had the highest prevalence rate (3.0%) of persistent low WBC counts (3 consecutive low WBC counts) compared to the rate for the entire NWC population (1.2%). However, rates for persistent low WBC counts were based on few cases and the difference did not reach statistical significance. The high rate in Thompson Laboratory was almost entirely attributable to the presence of employees of the Electronic Warfare Department who comprised nearly 90% of participants from this laboratory. Thompson laboratory workers not in the Electronic Warfare Department did not have a high rate of low WBC counts.
4. The high rate of low WBC counts in the Electronic Warfare Department is due to the statistically significanthigh rate (26.0%) in the Microwave Development Division. The distribution of white blood cell in this division shows a marked shift toward lower white blood cell counts.

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APPENDIX A

Appendix A

Appendix Table A1. Study participation rate by grouped work code, Naval Weapons Center, China Lake, California, 1982-83

Grouped work code	Number of personnel	Number participating	Percent participating
1. Administration	256	196	77
2. Support department	958	466	49
3. Research department	238	159	67
4. Engineering department	558	383	69
5. Aircraft weapons	288	214	74
6. Ordnance department	277	221	80
7. Fuze and sensors	260	224	86
8. Electronic Warfare dept.	320	235	73
9. Weapons department	370	220	59
10. Aircraft department	71	51	72
11. Range department	344	202	59
12. Unknown	641	441	69
Total	4,581	3,012	66

Table A2. Crude and Smoking Adjusted Rate for Study Subjects with White Blood Cell Counts ≤4,500 Cells per mm,[3] According to Detailed Work Code, Naval Weapons Center, China Lake, 1982-83

Work code	No. of Cases	No. of employee Participants	Rate per 100 of WBCC ≤4,500 cells/mm^3	Confidence limits Lower	Confidence limits Upper	Smoking adjusted rate per 100 of WBCC ≤4,500 cell/mm^3	Confidence limit Lower	Confidence limit Upper
1. NWC Command	7	122	5.7	1.6	9.9	5.0	0.0	10.5
2. Office of Finance and Management	11	181	6.1	2.6	9.6	6.4	1.9	10.9
3. Personnel Department	7	64	10.9	3.3	18.6	11.2	2.2	20.2
4. Weapons Planning Group	5	39	12.8	2.3	23.3	12.0	0.6	21.4
5. NRMC Branch Medical Clinic	1	32	3.1	0.0	9.1	3.4	0.0	11.2
6. Recreational Services Department	0	16	0.0	0.0	0.0	0.0	0.0	0.0
7. NRDC Branch Dental Clinic	1	16	6.2	0.0	18.1	10.3	0.0	32.3
8. Safety and Security Department	8	113	7.1	2.3	11.8	8.1	1.5	14.6
9. Supply Department	1	121	0.8*	0.0	2.4	0.9	0.0	3.0
10. Public Works Department	7	235	3.0*	0.8	5.1	3.6	0.5	6.6
11. Navy Exchange	0	4	0.0	0.0	0.0	0.0	0.0	0.0
12. Aircraft Weapons Integration Department	15	206	7.3	3.7	10.8	6.8	1.9	11.7
13. Ordnance Systems Command	4	112	3.6	0.1	7.0	4.0	0.0	8.4
14. Conventional weapons	5	56	8.9	1.5	16.4	8.6	0.3	16.9
15. Propulsion Systems Division	3	58	5.2	0.0	10.9	4.7	0.0	10.8
16. Fuze and Sensor Department Command	0	19	0.0	0.0	0.0	0.0	0.0	0.0
17. Sensor Systems Division	1	48	2.1*	0.0	6.1	1.7	0.0	5.8
18. Fuze System Division	5	60	8.3	1.3	15.3	6.8	0.1	13.5
19. Electromechanical Division	5	49	10.2	1.7	18.7	9.3	0.3	18.2
20 Survivability and Lethality Division	4	36	11.1	0.8	21.4	9.0	0.0	18.8

Table A2. Continued

Work code	No. of Cases	No. of employee Participants	Rate per 100 of WBCC ≤4,500 cells/mm^3	Confidence limits Lower	Confidence limits Upper	Smoking adjusted rate per 100 of WBCC ≤4,500 cell/mm^3	Confidence limit Lower	Confidence limit Upper
21. Technic ! Information Development	14	105	13.3	6.8	19.8	12.6	5.6	19.7
22. Electronic Warfare Command	20	123	15.6**	9.3	21.9	14.8	7.2	22.3
23. Microwave Development Division	13	50	26.0**	13.8	38.2	24.7	8.0	40.9
24. EMTES Division	2	62	3.2	0.0	7.6	3.9	0.0	10.1
25. Engineering Department	30	320	9.4	6.2	12.6	10.1	6.1	14.1
26. Research Department Command	1	5	20.0	0.0	55.1	14.4	0.0	44.3
27. Psychics Division	5	47	10.6	1.8	19.4	16.2	0.0	39.8
28. Chemistry Division	4	32	12.5	1.0	24.0	11.1	0.0	22.9
29. Computer Science Division	5	58	8.6	1.4	15.8	8.6	0.0	18.4
30. Aerothermochemistry Division	1	19	5.3	0.0	15.3	5.2	0.0	16.6
31. Weapons Department Command	2	47	4.3	0.0	10.0	3.8	0.0	9.8
32. Weapons Department Program Managers	0	22	0.0	0.0	0.0	0.0	0.0	0.0
33. Weapons Synthesis Division	1	26	3.8	0.0	11.2	3.0	0.0	9.8
34. Weapons Development Division	1	50	2.0*	0.0	5.9	2.0	0.0	6.4
35. Electro-Optics Division	3	38	7.9	0.0	16.5	7.7	2.0	17.5
36. Radio Frequency Division	0	44	0.0	0.0	--	0.0	0.0	—
37. Aircraft Department Command	4	23	17.4	1.9	32.9	16.5	0.0	37.6
38. Target Division	2	12	16.7	0.0	37.7	20.6	0.0	49.1
39. Ordnance Division	1	13	7.7	0.0	22.2	4.0	0.0	17.6
40. Range Department Command	2	6	33.3	0.0	71.0	36.1	0.0	77.8

Table A2. Continued

Work code	No. of Cases	No. of employee Participants	Rate per 100 of WBCC $\leq$4,500 cells/mm^3	Confidence limits Lower	Confidence limits Upper	Smoking adjusted rate per 100 of WBCC $\leq$4,500 cell/mm^3	Confidence limit Lower	Confidence limit Upper
41. Ordnance Test and Evaluation Division	1	55	1.8	0.0	5.3	2.1	0.0	6.9
42. Range Operations Division	7	65	10.8	3.2	18.3	13.0	2.7	23.2
43. Range Instrumentation Support Div.	2	47	4.3	0.0	10.0	6.4	0.0	22.7
44. Telemetry Division	1	28	3.6	0.0	10.4	4.0	0.0	13.0
45. Parachute Systems Department	7	68	10.3	3.1	17.5	9.0	1.7	16.4
46. Attached Activities	3	50	6.0	0.0	12.6	6.8	0.0	16.5
Unknown	0	5	0.0	0.0	--	0.0	0.0	--
Total	222	3,012	7.4	6.4	8.3	7.4	6.3	8.6

Appendix Table A3. Mean white blood cell count by work location and smoking status, Naval Weapons Center, China Lake, California, 1982-83

	Work location	Current Smoker				Non-smoker				Total			
		No.	Mean WBC $\times 10^{-3}$ per mm^3	95% Confidence limits Lower	Upper	No.	Mean WBC $\times 10^{-3}$ per mm^3	95% Confidence limits Lower	Upper	No.	Mean WBC $\times 10^{-3}$ per mm^3	95% Confidence limits Lower	Upper
1.	Administration bldg.	42	8.5	7.7	9.3	88	6.6	6.3	7.0	130	7.2	6.9	7.6
2.	Air facility	70	8.0	7.4	8.5	158	6.1	5.8	6.4	228	6.7	6.4	7.0
3.	Area R and extension	23	7.8	6.9	8.8	66	6.3	5.9	6.7	89	6.7	6.4	7.2
4.	CL pilot plant	18	7.4	6.5	8.3	39	6.2	5.7	6.7	57	6.5	6.1	7.1
5.	CLPP administration area	15	8.0	6.7	9.2	45	6.2	5.8	6.6	60	6.6	6.2	7.1
6.	CT/sky top area	11	9.2	7.3	11.1	25	6.6	6.1	7.1	36	7.4	6.7	8.2
7.	Echo range	23	10.7*	9.2	12.1	41	7.3	6.7	8.0	64	8.5*	7.8	9.3
8.	Fire station	29	8.5	7.2	9.7	26	5.8	5.2	6.4	55	7.2	6.4	8.0
9.	Lauritsen laboratory	8	8.3	7.1	9.5	66	6.2	5.9	6.6	74	6.5	6.1	6.8
10.	Magazine area	5	7.2	5.0	9.4	3	5.8	3.4	8.2	8	6.7	5.3	8.0
	Michelson laboratory												
11.	Engineering labs	23	7.6	6.8	8.5	70	6.4	6.0	6.8	93	6.7	6.3	7.1
12.	Photography lab	7	8.8	6.9	10.7	19	5.9	5.2	6.6	26	6.7	5.8	7.5
13.	Propulsion lab	3	7.7	5.9	9.4	3	5.7	3.7	7.7	6	6.7	5.4	8.0
14.	Wing 4	9	8.2	6.3	10.0	34	6.4	6.0	6.8	43	6.8	6.3	7.3
15.	Wing 6	16	8.5	7.5	9.6	43	6.2	5.6	6.7	59	6.8	6.3	7.3
16.	Other	118	8.1	7.7	8.5	411	6.1	6.0	6.3	529	6.6+	6.4	6.7

Appendix Table A3. (Cont'd)

	Smoking Status								Total			
	Current Smoker				Non-smoker							
Work location	No.	Mean WBC X 10^{-3} per mm^3	95% Confidence limits Lower	Upper	No.	Mean WBC X 10^{-3} per mm^3	95% Confidence limits Lower	Upper	No.	Mean WBC X 10^{-3} per mm^3	95% Confidence limits Lower	Upper
17. Old dorm, personnel housing	50	8.2	7.6	8.7	119	6.1	5.8	6.3	169	6.7	6.4	7.0
18. On the road	3	7.3	3.9	10.7	8	6.5	5.6	7.5	11	6.8	6.0	7.5
19. Public works compound	25	9.5	8.1	11.0	71	6.5	6.5	6.2	96	7.3	6.8	7.8
20. Ranges	42	8.3	7.6	9.1	89	6.6	6.2	7.1	131	7.2	6.8	7.5
21. Safety and security	8	7.9	6.8	9.0	27	7.0	6.2	7.8	35	7.2	6.6	7.8
22. Salt wells pilot plant	20	9.0	7.8	10.2	78	6.1	5.8	6.5	98	6.7	6.3	7.1
23. Supply dept warehouse	20	9.6	8.5	10.8	35	7.6*	6.9	8.2	55	8.3*	7.7	8.9
24. Solid dept. warehouse	4	8.7	3.4	13.9	28	6.2	5.7	6.6	32	6.5	5.9	7.1
25. Thompson laboratory	15	8.0	6.5	9.5	83	5.8	5.5	6.2	98	6.1+	5.8	6.5
26. Other areas	57	8.2	7.6	8.7	216	6.5	6.2	6.7	273	6.8	6.6	7.0
27. Unknown	161	8.4	8.1	8.7	261	6.5	6.3	6.7	457**	7.2*	7.0	7.4
Total	825	8.4	8.2	8.6	2,152	6.3	6.2	6.4	3,012	6.9	6.8	6.9

*Significantly high at the $p \le 0.05$ level.

+Significantly low at the $p \le 0.05$ level.

**Includes 35 with unknown smoking status.

Appendix Table A4.- Prevalence rate of study subjects having two consecutive low white blood cell counts, ($\leq$4,500 cells per mm^3), by grouped work code, Naval Weapons Center, China Lake, California, 1982-83

Grouped work codes	Current smokers: No. of cases	Current smokers: No. of participants	Current smokers: Rate per 100	Current smokers: 95% Confidence limits Lower	Current smokers: 95% Confidence limits Upper	Non-smokers: No. of cases	Non-smokers: No. of participants	Non-smokers: Rate per 100	Non-smokers: 95% Confidence limits Lower	Non-smokers: 95% Confidence limits Upper	Total: No. of cases	Total: No. of participants	Total: Rate per 100	Total: 95% Confidence limits Lower	Total: 95% Confidence limits Upper
1. Administration	0	141	0.0	0.0	--	12	363	2.9	1.4	5.3	12	504	2.1	1.0	3.8
2. Medical clinic	0	16	0.0	0.0	--	0	28	0.0	0.0	--	0	44	0.0	0.0	--
3. Support depts.	0	209	0.0	0.0	--	3	328	1.0	0.2	2.8	3	537	0.6	0.1	1.8
4. Research dept.	1	32	3.2	0.1	18.1	5	129	3.9	1.3	9.1	6	161	3.8	1.4	8.2
5. Engineering dept.	0	116	0.0	0.0	--	9	269	3.4	1.6	6.4	9	385	2.4	1.1	4.5
6. Aircraft weapons integ. dept.	0	29	0.0	0.0	--	6	174	3.5	1.3	7.6	6	203	3.0	1.1	6.6
7. Ordnance system dept.	0	59	0.0	0.0	--	5	161	[illegible].2	1.0	7.5	5	220	2.3	0.8	5.4
8. Fuze and sensors	0	31	0.0	0.0	--	7	180	4.0	1.6	8.1	7	211	3.4	1.4	7.0
9. Electronic warfare dept.	0	59	0.0	0.0	--	14	177	8.1*	4.4	13.6	14	236	6.1*	3.3	10.2
10. Weapons dept.	0	48	0.0	0.0	--	3	179	1.7	0.4	5.0	3	227	1.4	0.3	4.0
11. Aircraft dept.	2	21	9.5	1.2	34.4	1	27	3.7	0.1	20.6	3	48	2.1	0.0	11.6
12. Range dept.	0	62	0.0	0.0	--	0	135	0.0	0.0	--	0	197	0.0	0.0	--
13. Unknown	0	2	0.0	0.0	--	0	2	0.0	0.0	--	0	35+	0.0	0.0	--
Total	3	825	0.4	0.1	1.0	65	2,152	2.9	2.3	3.8	68	3,012	2.3	1.7	2.8

*Significantly high at the . $\leq$ 0.05 level.

+Includes 31 with unknown smoking status.

Appendix Table A5. Prevalence rate of study subjects having two consecutive low white blood cell counts ($\leq$4,500 cells per mm^3) by work location, Naval Weapons Center, China Lake California, 1982-83

	Work location	Current smokers					Non-smokers					Total				
		No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	Upper
1.	Administration bldg.	0	42	0.0	0.0	--	4	88	4.6	0.2	8.9	4	130	3.1	0.1	6.0
2.	Air facility	2	70	2.9	0.0	6.8	6	158	3.[illegible]	0.8	6.8	8	228	3.5	1.1	5.9
3.	Area R and extension	0	23	0.0	0.0	--	4	66	6.1	0.3	11.8	4	89	4.5	0.2	8.8
4.	CL pilot plant	0	18	0.0	0.0	--	1	39	2.6	0.0	7.5	1	57	1.8	0.0	5.2
5.	CLPP administration area	0	15	0.0	0.0	--	0	45	0.0	0.0	0.0	0	60	0.0	0.0	--
6.	CT/sky top area	0	11	0.0	0.0	--	0	25	0.0	0.0	--	0	36	0.0	0.0	--
7.	Echo range	0	23	0.0	0.0	--	0	41	0.0	0.0	--	0	64	0.0	0.0	--
8.	Fire station	0	29	0.0	0.0	--	1	26	3.8	0.0	11.2	1	55	1.8	0.0	5.3
9.	Lauritsen laboratory	0	8	0.0	0.0	--	2	66	3.0	0.0	7.2	2	74	2.7	0.0	6.4
10.	Magazine area	0	5	0.0	0.0	--	0	3	0.0	0.0	--	0	8	0.0	0.0	--
	Michelson laboratory															
11.	Engineering labs	0	23	0.0	0.0	--	0	70	0.0	0.0	--	0	93	0.0	0.0	--
12.	Photography lab	0	7	0.0	0.0	--	0	19	0.0	0.0	--	0	26	0.0	0.0	--
13.	Propulsion lab	0	3	0.0	0.0	--	0	3	0.0	0.0	--	0	6	0.0	0.0	--
14.	Wing 4	0	9	0.0	0.0	--	0	34	0.0	0.0	--	0	43	0.0	0.0	--
15.	Wing 6	0	16	0.0	0.0	--	1	43	2.3	0.0	6.8	1	59	1.7	0.0	5.0
16.	Other	1	118	0.8	0.0	2.5	18	411	4.4	2.4	6.4	19	529	3.6	2.0	5.2

Appendix Table A5.(Cont'd)

	Work location	Current smokers					Non-smokers					Total				
		No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	95% Confidence limits Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	95% Confidence limits Upper	No. of cases	No. of parti-cipants	Rate per 100	95% Confidence limits Lower	95% Confidence limits Upper
17.	Old dorm, personnel housing	0	50	0.0	0.0	--	3	119	2.5	0.0	5.3	3	169	1.8	0.0	3.8
18.	On the road	0	3	0.0	0.0	--	0	8	0.0	0.0	--	0	11	0.0	0.0	--
19.	Public works compound	0	25	0.0	0.0	--	1	71	1.4	0.0	4.1	1	96	1.0	0.0	3.1
20.	Ranges	0	42	0.0	0.0	--	2	89	2.2	0.0	5.3	2	131	1.5	0.0	3.6
21.	Safety and security	0	8	0.0	0.0	--	0	27	0.0	0.0	--	0	35	0.0	0.0	--
22.	Salt wells pilot plant	0	20	0.0	0.0	--	2	78	2.6	0.0	6.1	2	98	2.0	0.0	4.8
23.	Supply dept warehouse	0	20	0.0	0.0	--	0	35	0.0	0.0	--	0	55	0.0	0.0	--
24.	Solid dept. warehouse	0	4	0.0	0.0	--	0	28	0.0	0.0	--	0	32	0.0	0.0	--
25.	Thompson laboratory	0	15	0.0	0.0	--	7	83	8.4	2.5	14.4	7	98	7.1	2.0	12.2
26.	Other areas	0	57	0.0	0.0	--	7	216	3.2	0.9	5.6	7	273	2.6	0.7	4.4
27.	Unknown	0	161	0.0	0.0	--	0	261	0.0	0.0	--	6	457*	1.3	0.3	2.4
	Total	3	825	0.4	0.0	0.8	59	2,152	2.7	2.1	3.4	68	3,012	2.3	1.7	2.8

*Includes 33 people with unknown smoking status.

Appendix Table A6. White Blood Cell Counts of Study Participants with at Least One Count $\leq$4,500 Cells per mm^3, Electronic Warfare Department, Naval Weapons Center, China Lake, 1982-83

	1982						1983						All blood draws combined	
	1st blood draw		2nd blood draw		3rd blood draw		1st blood draw		2nd blood draw		3rd blood draw			
Study subject	Date	Count	Date	Count	Date	Count	Date	Count	Date	Count	Date	Count	Mean	S.D.
1.	5/6	4.11	6/9	4.36	7/12	5.35	7/21	3.90	8/23	5.20	--	--	4.58	0.65
2.	4/20	3.77	5/19	4.18	--	--	--	4.45	8/22	4.86	--	--	4.32	0.46
3.	4/20	3.49	6/7	3.46	7/19	3.65	7/18	4.70	--	--	--	--	3.82	0.59
4.	4/20	3.74	6/7	5.16	--	--	7/27	4.21	8/29	4.65	--	--	4.44	0.61
5.	4/20	4.15	6/7	3.72	7/7	4.36	8/15	4.56	--	--	--	--	4.20	0.36
6.	5/6	4.14	6/9	4.93	--	--	7/21	4.30	8/23	5.71	--	--	4.77	0.71
7.	4/30	4.15	6/7	4.25	7/8	4.43	8/19	4.39	--	--	--	--	4.31	0.13
8.	4/20	4.17	6/7	3.98	7/19	6.77	--	--	--	--	--	--	4.97	1.56
9.	4/30	3.62	6/2	4.12	7/7	4.82	--	--	--	--	--	--	4.19	0.60
10.	4/30	4.27	6/16	4.98	--	--	6/14	4.89	--	--	--	--	4.71	0.39
11.	5/7	4.40	6/14	3.56	7/14	4.03	--	--	--	--	--	--	4.00	0.42
12.	5/7	4.27	6/14	4.68	--	--	7/15	5.06	--	--	--	--	4.67	0.40
13.	5/6	4.18	6/9	7.82	--	--	7/21	5.61	--	--	--	--	5.87	1.83
14.	5/6	4.07	6/9	4.67	--	--	7/21	4.50	--	--	--	--	4.41	0.31
15.	5/8	3.48	6/14	3.13	7/14	3.09	--	--	--	--	--	--	3.23	0.21
16.	3/29	3.98	5/19	3.96	6/23	4.34	--	--	--	--	--	--	4.09	0.21
17.	5/7	4.28	6/14	5.19	--	--	7/21	4.90	--	--	--	--	4.79	0.46
18.	4/30	3.36	6/2	2.77	10/8	2.76	--	--	--	--	--	--	2.96	0.34
19.	4/30	4.06	6/2	3.85	7/7	4.58	--	--	--	--	--	--	4.16	0.38
20.	4/30	3.89	6/7	4.25	7/8	4.90	--	--	--	--	--	--	4.35	0.51

Appendix Table A6. (Cont'd)

			1982						1983					
	1st blood draw		2nd blood draw		3rd blood draw		1st blood draw		1st blood draw		3rd blood draw			
	Date	Count	Date	Count	Date	Count	Date	Count	Date	Count	Date	Count	Mean	S.D.
21.	5/4	5.46	--	--	--	--	7/21	4.00	8/24	5.42	--	--	4.96	0.83
22.	4/28	5.17	--	--	--	--	7/28	3.17	9/6	4.37	10/1	3.7	4.24	1.01
23.	5/6	3.90	6/23	4.78	--	--	--	--	--	--	--	--	4.34	0.62
24.	8/11	4.20	9/13	5.67	--	--	--	--	--	--	--	--	4.94	1.04
25.	5/6	4.13	6/9	5.79	--	--	--	--	--	--	--	--	4.96	1.17
26.	3/8	4.16	--	--	--	--	7/28	4.09	--	--	--	--	4.13	0.05
27.	5/6	4.32	6/9	4.82	--	--	--	--	--	--	--	--	4.57	0.35
28.	5/6	3.55	6/9	5.15	--	--	--	--	--	--	--	--	4.35	1.13
29.	4/20	4.04	6/7	4.17	--	--	--	--	--	--	--	--	4.38	0.47
30.	4/28	4.45	6/1	6.47	--	--	--	--	--	--	--	--	5.46	1.43
31.	3/15	4.39	4/19	4.52	--	--	--	--	--	--	--	--	4.46	0.09
32.	11/8	4.42	1/5	5.28	--	--	--	--	--	--	--	--	4.85	0.61
33.	5/7	3.86	6/14	4.68	--	--	--	--	--	--	--	--	4.27	0.58
34.	4/30	3.98	6/2	5.08	--	--	--	--	--	--	--	--	4.53	0.78
35.	3/15	4.02	--	--	--	--	--	--	--	--	--	--	4.02	--
36.	5/6	4.46	--	--	--	--	--	--	--	--	--	--	4.46	--
37.	5/7	4.44	--	--	--	--	--	--	--	--	--	--	4.44	--

APPENDIX B

Appendix B

Table B1. Electronic Warfare Department Groupings based on the 1981 Naval Weapons Center Code Directory, China Lake, 1982-83.

Electronic Warfare Department	Codes
Administration (Department Staff and the HARM Program Office)	35, 35A, 35069, 3509, 3506, 3506A,
System Science Division	351, 35101, 3511, 3512-14, 3517
Rf Development Division	352, 35201, 35203, 35204, 3521-3, 3525
Microwave Development Division	354, 35401, 3541-4
EWTES Division	355, 35503, 3551, 3553-4, 3556

APPENDIX C

Appendix C

White Blood Cell Counts

at the Naval Weapons Center

China Lake, CA

By:

A. Owen
J. Friedman
H. Solomon

Department of Statistics
Stanford University

July 1986

1. Introduction

During the period February 1982 through March 1983, the Naval Weapons Center (NWC), China Lake and the Naval Health Research Center (NHRC), San Diego conducted a hematological monitoring program for all NWC employees. Objectives of the program included development of a hematological profile of the work force at NWC and evaluation of the health significance of the profile. All in all 3,012 persons at the NWC center participated in the program.

The primary focus of the China Lake monitoring program was on white blood cell counts. Persons with white blood counts (WBCs) below 4,500 were identified for further testing. White blood cell count distribution patterns were examined for groups of employees. These groupings were by smoker/non-smokers, by occupation, by organizational unit and by geographical location within NWC. One organizational unit showed a white blood cell count distribution pattern that appeared different from the composite for the NWC as a whole (see Fig. 1). This unit is referred to as MDD in this report.

The Stanford Statistics Department was asked to assess the statistical difference between the data for the non-smokers in the MDD group and the non-smokers for the rest of the Naval weapons Center. The major element confusing the significance of the distribution for the non-smoker MDD group was the small size of the sample. There were only 39 persons in the MDD non-smoker group as compared to 2,106 in the non-smoker group for the rest of NWC.

From Figure 1 it is possible to recover the number of nonsmoking NWC personnel in each subrange to a high degree of accuracy and to obtain exact numbers of nonsmoking MDD personnel in each subrange. These numbers are given Figure 2.

Section 2 assesses the differences between the groups in terms of statistical significance. The significance is the probability of getting 39 WBCs that differ from the norm as much as the MDD group's do, under the assumption that the MDD group's WBCs are a sample from the same distribution as the non-MDD WBCs.

Section 3 addresses the practical significance of the differences between groups. For this a 95% confidence interval for the amount by which the MDD group's WBCs are lowered is computed.

Section 4 summarizes the conclusions of this investigation, and refers to follow-up work.

2. Statistical Significance

The 2145 nonsmoking NWC personnel can be split into two groups for the purpose of this analysis. The first group is the 39 MDD personnel and the second is the 2106 non-MDD personnel.

The WBCs for the MDD group had a mean of 5300 and a standard deviation of 1300. The WBCs for the others had a mean of 6400 and a standard deviation of 1600. The two sample t statistic to compare these groups is

$$
\begin{aligned}
t &= \frac{5300 - 6400}{\sqrt{\frac{38 \cdot 1300^2 + 2105 \cdot 1600^2}{39+2106-2}}\sqrt{\frac{1}{39} + \frac{1}{2106}}} \\
&= -4.3.
\end{aligned}
$$

The probability of a t statistic this extreme is

$$P(|t_{(2143)}| \geq 4.3) = 1.8 \times 10^{-5}$$

or roughly 1 in 50,000.

Since there are so many people in the non-MDD group, it is reasonable to treat their mean WBC, 6400, as a known constant. Many statisticians would favor a one sample t-test to assess whether the mean WBC in the MDD group differs from 6400, because it does not rest on the assumption that the variances are equal in the two groups. The value of the one sample t statistic is

$$
\begin{aligned}
t &= \frac{5300 - 6400}{\sqrt{\frac{1300^2}{39}}} \\
&= -5.3
\end{aligned}
$$

and $P(|t_{(38)}| \geq 5.3) = 5 \times 10^{-6}$ which is 1 in 200,000.

Both t-tests lead to the same conclusion: the mean WBC is lower in the MDD group.

Sometimes a small significance level does not provide strong evidence. For example, if 100 t tests are conducted, it is not surprising to find one so extreme it could only arise by chance 1 time in 100. If 100 different groupings of employees were investigated, the chance of seeing one with a 1 in 50,000 significance level is no more than 1 in 500, so it is unlikely that the observed difference is a consequence of investigating many groupings.

The t-tests indicate that there are differences but they do not provide as detailed information as we might like, and they rest on an assumption of normality. Although the mean WBC is lower for the MDD group, it is of more direct importance to know if this group has too many WBCs below some threshold. A difference in the means might arise from the MDD group having too many

5000 WBCs and too few 7500s. The same difference in the means could arise from too many 2500s and too few 5000s and the latter may be medically more significant.

In the non-MDD group there were 64 WBCs less than 4000. This represents 3% of that group. If the 39 MDD WBCs were drawn from a population of which 3% were under 4000 then the number of them under 4000 would have a binomial distribution with $n = 39$ and $p = .03$. The expected number of such WBCs is $39 \times .03 = 1.2$. There were 4 such WBCs in the MDD group. The significance level of this, computed from the binomial distribution, is .03. Since we are not sure in advance which cutoff level to use, such p-values are calculated for all the cutoff levels. They appear in Figure 3.

The most significant cutoff value in Figure 3 is 5000. If the MDD group had the same distribution as the others, then 19% of them (roughly 7) should have WBCs under 5000. Instead 21 of them (over 50%) had WBCs under 5000. Under the binomial distribution this would happen by chance 1.3 times in 1,000,000. There appear to be too many MDD WBCs below cutoffs between 4000 and 7000 and there is strong evidence at cutoffs from 4500 through 6500.

Since 22 p-values were computed and the lowest was 1.3×10^{-6} the true significance level for the numbers in Figure 3 is between 1.3×10^{-6} and $22 \times 1.3 \times 10^{-6} = 2.9 \times 10^{-5}$; the upper bound is a Bonferonni bound.

A simulation was conducted for this problem. Of the 2106 numbers representing 2106 non-MDD WBCs, 39 were selected at random (with replacement). Therefore, these 39 numbers are exactly a sample of size 39 from the observed distribution of the non-MDD WBCs. The same calculations were done on these 39 numbers as are given in Figure 3. This was repeated until 1000 such random samples had been considered. For each of the 1000 repetitions 22 binomial p-values were calculated, and the minimum of the 22 p-values recorded. The smallest of the 1000 minima was 2.4×10^{-4}. The minima have a distribution that is very close to a Beta distribution with $\alpha = 1.2$ and $\beta = 8.04$. See Figure 4, for a QQ plot of the minima. [By way of reference, the minimum of 22 independent p-values would have a Beta distribution with $\alpha = 1$ and $\beta = 22$. The 22 p-values in each replication are dependent.]

Using the Beta approximation, the smallest of the 22 p-values should be less than .0114 to be significant at the 5% level and less than .0029 to be significant at the 1% level.

3. <u>Practical Significance</u>

The MDD group has lower WBCs than the other nonsmoking NWC personnel and the difference is not likely to have arisen purely by chance. In this section the magnitude of the difference is assessed.

Suppose that all of the WBCs in the MDD group were raised by 500. This would have the effect of shifting the MDD column in Figure 2 down 1 step. A minimal p-value for the shifted column can be calculated as before. The value obtained is .0056 which, by the Beta approximation, is significant at the 5% level. A shift of 500 for the MDD group still leaves their WBCs significantly low. A shift of 1000 produces a minimal p-value of .22 which is not statistically significant. A shift of 1500 produces a minimal p-value of .0030 which is close to the 1% significance level. In this case however the indication is that the MDD group shifted up by 1500 have WBCs that are too large. From this we can conclude that the WBCs in the MDD group are depressed by more than 500 but not by as much as 1500. The data suggest that the WBCs in the MDD group might be depressed by 1000 units, which agrees well with the observed difference of 1100 between the mean WBCs of the two groups.

Using the one sample t statistic a 95% confidence interval for the mean WBC is

$$\begin{aligned} & 5300 \pm t_{.025,38} 1300/\sqrt{39} \\ = \; & 5300 \pm 2.02 \times 1300/\sqrt{39} \\ = \; & 5300 \pm 400 \end{aligned}$$

Treating the mean WBC in the non-MDD group as a known constant (6400), the mean WBC in the MDD group is depressed by $6400 - 5300 \pm 400$, that is by an amount between 700 and 1500.

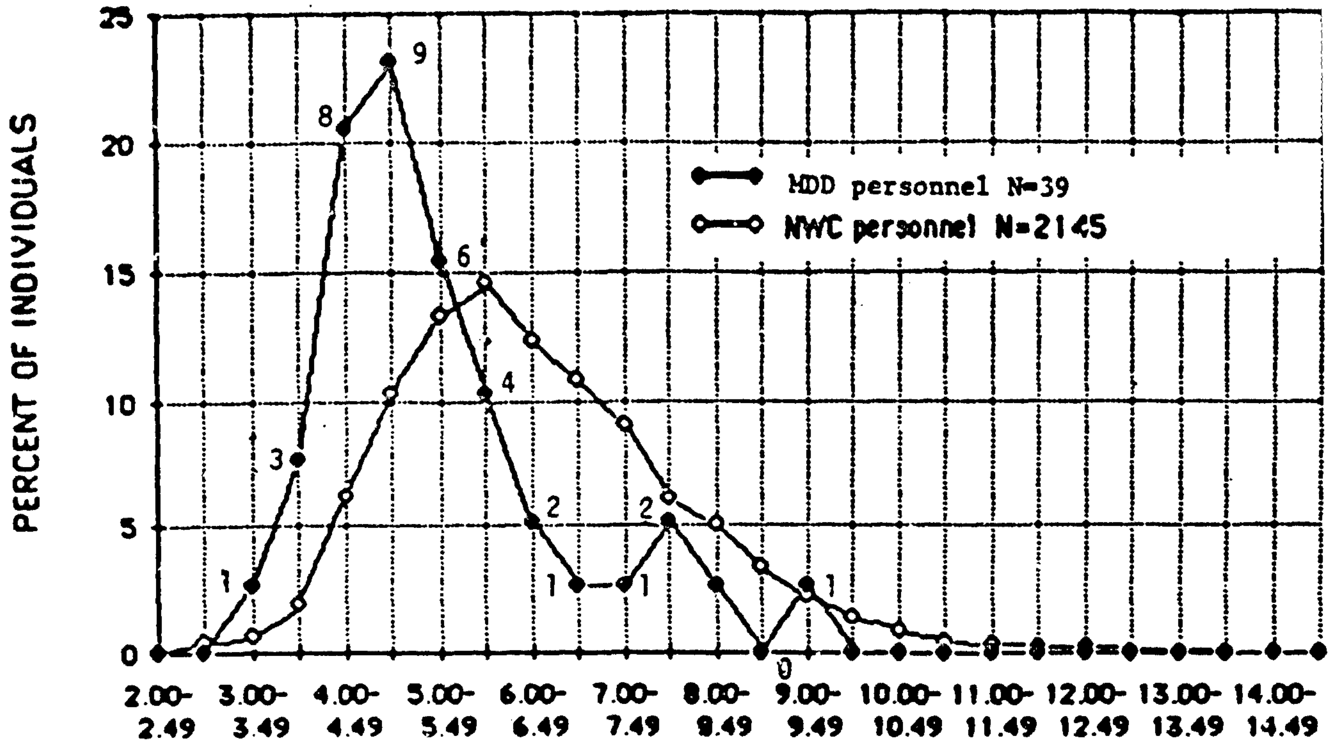
4. Conclusions

The WBCs for nonsmoking employees in the MDD group are lower than those of other nonsmoking employees of the NWC. The difference is very unlikely to have arisen by chance alone.

A t-test indicates that the average WBC is significantly lower for the MDD group. A more detailed analysis based on the binomial distribution indicates that the MDD group has an excess of WBCs under 5000, compared to the other nonsmoking NWC personnel. The excess is also noticeable at other cutoffs between 4500 and 6500.

Further analysis suggests that the WBCs in the MDD group are depressed by approximately 1000 per millimeter cubed. Using the binomial model one can conclude that if the whole MDD distribution has been shifted, then it has been shifted down by an amount greater than 500 but not as great as 1500. Using a t-statistic one can conclude that if the mean of the MDD distribution has been shifted, then it has been shifted down by an amount between 700 and 1500.

It is of interest to see if this is an anomaly. One way of investigating this is to undergo another experiment. We are designing several sampling plans, i.e. sample sizes for each of the two groups based on the information already on hand to assess whether the difference is genuine and persistent.



WBC Counts Times 10^{-3} Per Cubic Millimeter

Figure 1.

Distribution of white blood cell counts in percent for nonsmoking workers in the MDD group and all nonsmoking NWC personnel, 1982-83.

Source: Memorandum dated 5 Nov. 1985 from Carl Schaniel.

Figure 2. WBCs for nonsmoking personnel

Range*	# NWC	# MDD
2.0 ≤ WBC < 2.5	0	0
2.5 ≤ WBC < 3.0	11	0
3.0 ≤ WBC < 3.5	17	1
3.5 ≤ WBC < 4.0	40	3
4.0 ≤ WBC < 4.5	134	8
4.5 ≤ WBC < 5.0	220	9
5.0 ≤ WBC < 5.5	284	6
5.5 ≤ WBC < 6.0	310	4
6.0 ≤ WBC < 6.5	264	2
6.5 ≤ WBC < 7.0	232	1
7.0 ≤ WBC < 7.5	190	1
7.5 ≤ WBC < 8.0	131	2
8.0 ≤ WBC < 8.5	105	1
8.5 ≤ WBC < 9.0	71	0
9.0 ≤ WBC < 9.5	48	1
9.5 ≤ WBC < 10.0	31	0
10.0 ≤ WBC < 10.5	23	0
10.5 ≤ WBC < 11.0	14	0
11.0 ≤ WBC < 11.5	8	0
11.5 ≤ WBC < 12.0	6	0
12.0 ≤ WBC < 12.5	6	0
12.5 ≤ WBC < 13.0	0	0
	2145	39

* in 1000s/millimeter cubed

Figure 3

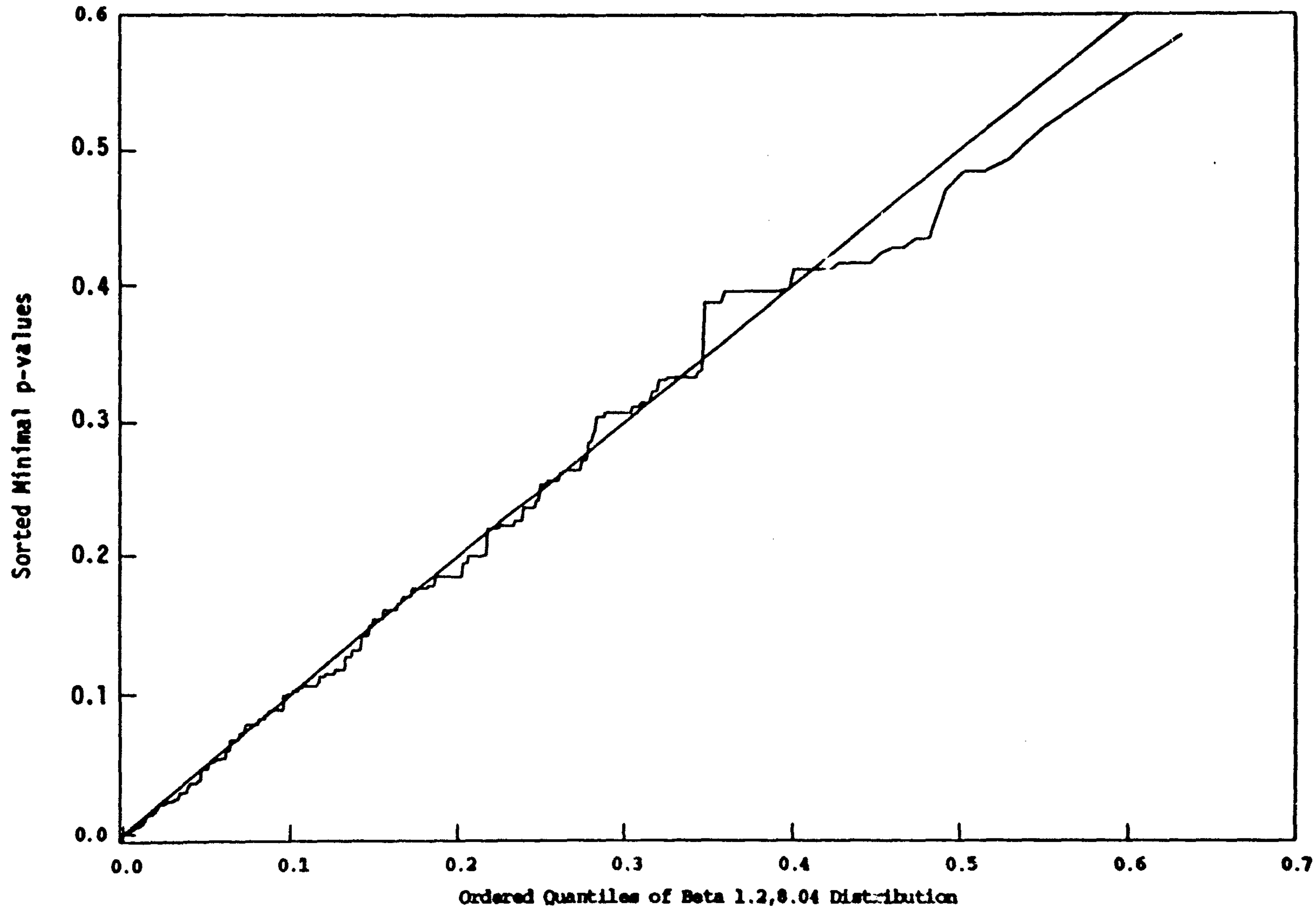
WBC Group	# non-MDD	% non-MDD	Expected # MDD	# MDD	Significance
< 2500	0	0.0	0.0	0	
< 3000	11	0.5	0.2	0	
< 3500	27	1.3	0.5	1	4.0×10^{-1}
< 4000	64	3.0	1.2	4	3.0×10^{-2}
< 4500	190	9.0	3.5	12	1.1×10^{-4}
< 5000	401	19.0	7.4	21	1.3×10^{-6}
< 5500	679	32.2	12.6	27	2.7×10^{-6}
< 6000	985	46.8	18.2	31	3.7×10^{-5}
< 6500	1247	59.2	23.1	33	9.2×10^{-4}
< 7000	1478	70.2	27.4	34	2.2×10^{-2}
< 7500	1667	79.2	30.9	35	1.2×10^{-1}
< 8000	1796	85.3	33.3	37	1.8×10^{-1}
< 8500	1900	90.2	35.2	38	5.2×10^{-1}
< 9000	1971	93.6	36.5	38	6.3×10^{-1}
< 9500	2018	95.8	37.4	39	
< 10000	2049	97.3	37.9	39	
< 10500	2072	98.4	38.4	39	
< 11000	2086	99.1	38.6	39	
< 11500	2094	99.4	38.8	39	
< 12000	2100	99.7	38.9	39	
< 12500	2106	100.0	39.0	39	
< 13000	2106	100.0	39.0	39	

Figure 4

QQ Plot of Simulated Minimum Binomial p-Values

Jagged line: simulated data

Straight line: exact for Beta (1.2, 8.04)



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12 PERSONAL AUTHOR(S) GARLAND, Frank C.; WHITE, Martin R.; SEAL, Grace M.; LUIKEN, George A.

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19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The Naval Weapons Center, China Lake, (NWC) in collaboration with the Naval Health Research Center conducted an NWC-wide surveillance program to determine the prevalence in the NWC work force of low white blood cell (WBC) counts (≤4,500 cells per mm^3), during 1982-83. A complete WBC count was performed on 3,012 NWC employees (66% of the total work force). If a person had three consecutive low WBC counts (one month apart), the person was considered to have a persistent low WBC count and was referred for an evaluation of bone marrow function. There was no consistent trend in mean WBC counts according to age, sex, or length of employment at NWC. Mean WBC count was 6,900 cells per mm^3. Current cigarette smokers had a markedly higher mean WBC count (8,400 cells per mm^3) than never smokers (6,200 cells per mm^3). On the first blood draw 222 (7.4%) participants had low WBC counts; of those, 35 (1.2%) remained low after three blood draws. The Electronic Warfare Department had both crude and smoking-adjusted prevalence rates of low WBC counts nearly double that of the total NWC population, a statistically significant difference.

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Within the Electronic Warfare Department the Microwave Development Division had a crude and smoking-adjusted prevalence rate approximately 3.5 times the total NWC population. This finding was statistically significant before and after adjusting for smoking. The high rate of low WBC counts in the Electronic Warfare Department is due to the statistically high rate (26.0%) in the Microwave Development Division which shows a marked shift toward lower WBC counts.